Measuring the Effectiveness of Materials Management for Industrial Construction Projects in Saudi Arabia

by

Ali S. Al-Darweesh

A Thesis Presented to the

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DHAHRAN, SAUDI ARABIA

In Partial Fulfillment of the
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In

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عمادة الدراسات العليا
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Dedication

To the souls of both children and women who lost their lives during a wedding ceremony at Qudeh. To my parents whose prayers helped me to work hard. To my wife, daughter, and two sons whose love and understanding encouraged me to give more. And last, but not the least, to Almighty God for His endless and countless blessings.

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I would like to thank general managers of the Technical Services Department, the Operation Department, and the Maintenance Department of ARRAZI for their support during this study.

ملخص الرسالة

اسم الطالب: علي بن سعيد الدرويش

عنوان البحث: قياس فعالية إدارة المواد في المشاريع الإنشائية في المملكة العربية السعودية.

مجال البحث: هندسة وإدارة التشييد.

تاريخ البحث: ديسمبر ١٩٩٩

تقوم إدارة المواد بدور فاعل في إنجاح المشاريع الصناعية وزيادة ربحيتها. فلقد دلت الدراسات التي أجريت سابقا على أن المواد تشكل ٦٠% من التكلفة الكلية للمشاريع الصناعية, كما أنها تتحكم بالجدول الزمني للمشروع بنسبة ٨٠%. لذلك فان الإدارة الفاعلة للمواد تمثل مجالا خصبا للتطوير والتوفير. فان تقليص ما نسبته ٢% من قيمة المواد سوف تزيد ربحية المشروع بنسبة ٢١% بناء على ربحية ٥ و٥٥% من تكلفة المشروع. إن من فوائد وجود نظام فاعل لإدارة المواد هو توفير المواد وقت الحاجة إليها, وزيادة إنتاجية العمال, وكذلك تقليص الفائض من المواد عند انتهاء المشروع. لقد قام مؤلف هذا البحث باستخدام اثني عشر مؤشرا معترف به في الأوساط الصناعية لقياس مدى فعالية إدارة المواد في المشاريع الصناعية الإنشائية ووضعها في قالب عملي. وبعد ذلك أجرى بحثا ميدانيا , شمل مشاريع الشركة السعودية للصناعات الأساسية (سابك) وشركة ارامكو السعودية, ومشاريع القطاع الخاص في المنطقة الشرقية من المملكة العربية السعودية. ولقد أظهرت الدراسة التي شارك فيها ١٧ مشروعا صناعيا واستغرقت عاما كاملا, مدى فعالية إدارة المواد في المشاريع الصناعية الإنشائية وبينت نقاط القوة والضعف فيها.

ماجستير علوم

جامعة الملك فهد للبترول والمعادن

الظهران, المملكة العربية السعودية

ديسمبر ١٩٩٩

THESIS ABSTRACT

FULL NAME OF STUDENT: ALI S. DARWEESH

TITLE OF STUDY : MEASURING THE EFFECTIVENESS OF MATERIALS MANAGEMENT FOR INDUSTRIAL CONSTRUCTION PROJECTS IN SAUDI ARABIA

MAJOR FIELD : CONSTRUCTION ENGINEERING AND MANAGEMENT

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Materials management plays a significant role in the success and profitability of industrial projects. Studies have indicated that materials constitute about 60% of total project cost, and control 80% of the project schedule. Hence, effective management of materials represents an area with great potential for improvement and saving. Based on 5.5% profit of project cost, a 2% reduction in materials cost will increase profit by 21%. Availability of materials, improvement in labor productivity, and reduction in materials surplus are advantages of having a materials management system. Using 12 key, industrially accepted measures of assessing effectiveness, the author devised a measuring model and conducted a field study to measure the effectiveness of the materials management process of industrial projects, covering both SABIC affiliates and Saudi Aramco industrial projects in the Eastern Province of Saudi Arabia. Seventeen industrial projects were field studied and it was found that the materials management process was well managed and satisfactorily effective.

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1. INTRODUCTION

The Kingdom of Saudi Arabia has experienced a massive construction program since the early seventies, which has resulted in the establishment of many construction companies. Most of these companies have faced a number of challenges including lack of local skilled labor and a shortage of locally produced building materials. While these problems have largely been overcome successfully, material management is a challenge that has continued to cause a major obstacle to the success and profitability of many construction projects.

Material management is the planning and controlling of all necessary efforts to ensure that the correct quality and quantity of materials and installed equipment are appropriately specified in a timely manner, are obtained at reasonable cost, and are available when needed (The Business Roundtable 82)

Since materials constitute about 60% of the project cost (BRT 1983), it represents an area with great potential for improvement and saving. It was found that delay in delivering materials is the major cause of failure to finish projects on time (CII Project Materials Planning Guide 1987).

Materials control, according to an experienced project manager (Kerridge 1987A), accounts for 80% of project schedule. Since the profit is 5.5 % of total project cost (Business Roundtable Report 1983), a 2% cut in cost of materials will increase profit by 21% (Otaibi 1995).

After realizing the high cost of stockout or shortage cost on construction projects, construction companies were tempted to increase their inventory levels. This resulted in the increase of the carrying cost. In manufacturing, it was reported to be in the order of 25-35% of average inventory value per year (Otaibi 1995). Hence the surplus is estimated to be around 1.8% of the total materials cost of a project (BRT 1983). This appears to be a no-win situation in which too much inventory will increase carrying cost, while too little inventory may create shortages which means a delay in project completion. Obviously, neither situation is desirable.

In view of the above, the need to implement an effective materials management system in construction is highly desirable. Even more important is the need to measure the effectiveness of those systems already in place.

It was reported that a basic materials management system can be expected to produce a 6% improvement in craft labor productivity. When a sophisticated system is used, an additional 4-6% in craft labor savings can be expected (CII Research Project 1986). A substantial reduction in materials surplus of 3% is expected, (CII 1986). Conversely, the lack of effective materials management practices has resulted in an work-hour overrun of 18% (Randolph et al. 1989).

Construction companies must measure the effectiveness of their materials management process to be able to analyze the impact of process changes on process performance (James and Bell 1995); and to evaluate the need to implement a new materials system. With globalization in mind, the future will be with those companies who are continuously seeking improvements through the vigorous endeavor of processes to try to optimize profit. Construction companies in Saudi Arabia, in particular, will face tough competition from international companies who will operate freely in the Kingdom after the signing of the GATT Treaty, Saudi Arabia is also currently negotiating to join the World Trade Organization (WTO). Membership will force the construction companies in Saudi Arabia to minimize their operating cost, enhance their efficiencies, and improve their effectiveness. To date, no study has been conducted in the Kingdom to assess the effectiveness of the materials management process. Hence the proposed study is of paramount importance.

1.1 Research Objectives

The objectives of this study are:

1. To utilize an effectiveness-measuring model for materials management for industrial projects in Saudi Arabia.
2. To measure the effectiveness of the materials management processes of the industrial projects of construction companies operating in Saudi Arabia.
3. To use the result of the study as a basis for benchmarking future projects.

1.2 Methodology

The research approach was composed of three steps.

1. Identification of 12 key effectiveness measures of materials management as shown by Plemmons (1995).
2. Utilization of the model in the measurement of the effectiveness of materials management in industrial projects in Saudi Arabia.
3. Identification of the strengths and weaknesses of the materials management processes in use.

1.3 Scope and Limitation

This study measures the effectiveness of the materials management process of on going or newly completed industrial projects in the Eastern Province. An industrial project is defined by the Ministry of Housing and Public Works to include: industrial plants; refinery and petrochemical plants; oil and gas pipelines; and water desalination (MHPW Classification 1413).

It was not anticipated from the start of the study that all companies would give permission to conduct such a study in their projects. All efforts, however, were made to secure the required permits.

2. LITERATURE REVIEW

To gain a comprehensive understanding of material management, several articles were reviewed and summarized in the following formats: materials management processes, materials management functions, performance categories, key effectiveness measures, computer systems, and benchmarking.

2.1 Materials Management Process

To understand the process of materials management, an exact definition of the process is required. Three definitions were noted here with slight differences. The Business Roundtable (1982) defined materials management as:

> *The planning and controlling of all necessary efforts to ensure that the correct quality and quantity of materials and installed equipment are appropriately specified in a timely manner, are obtained at a reasonable cost, and are available when needed (BRT 1982).*

Stukhart (1989) provided another definition for materials management:

> *The planning, controlling, and integration of the materials takeoff, purchasing, economic, expediting, transportation, warehousing, and issue functions in order to achieve a smooth, timely, efficient flow of materials to the project in the required quantity, the required time, and at an acceptable price and required quality, and the planning and controlling of these functions (Stukhart 1989).*

Frederick (1991) provided another definition:

> *Materials management as practiced in the construction industry is the planning, executing, and controlling of all activities influencing the flow of materials to and through the jobsite. These activities include the design of the structure, material requirements and project planning, requisitioning of materials, purchasing materials, expediting shop drawing approval and material fabrication and delivery, shipping the materials, receiving the material at site or other storage location, and storing and handling the material (Frederick 1991).*

Being a process, materials management encompasses activities that are not limited to the organization boundary. It crosses the organization boundary to reach outside organizations such as that of vendors and subcontractors.

> *Project materials management should be thought of as a process rather than an organization. In fact, the activities of the materials cycle cross all organizational lines of the project and begin with the specification of the material which is primarily the responsibility of the owner and engineer (CII Project Materials Planning Guide 1987).*

The management of materials plays a major role in the success or the failure of a construction project.

> *The cost of materials represents more than half the total cost of today's typical capital project. Lack of materials when needed at the job site is typically the single most frequent cause of construction delays. Given the impact on cost and schedule, it is easy to see the positive influence that effective materials management can have on the cost of construction (CII Handbook 1987).*

Starting from the project conceptual design and estimation, and continuing through the detailed design and procurement up to the construction and start up stage, materials management responsibilities should be well defined all the way.

Materials management is a clearly defined task that, when properly planned and executed, provides project management with an invaluable tool to optimize schedules and improve labor productivity (Bell and Stukhart 1987).

Engineers, procurement coordinators, and construction personnel are all performing materials management activities.

Materials management is a system that includes all the functions of acquiring and distributing the materials and equipment to support construction. The objectives of this system include:

- *Obtaining the best value for purchased materials,*
- *Assuring supplies are on hand when and where required,*
- *Reducing inventory to the lowest amount required,*
- *Assuring quality requirements are met, and*
- *Providing efficient, low cost transport, security, and storage of materials at construction sites (CII Handbook 1987).*

Construction Industry Institute (CII) studies indicate that materials management is a major target area where substantial improvement in the design/ construction process can be achieved.

2.2 Materials Management Functions

Being a process, materials management consists of interdependent and integrated functions. These functions are materials takeoff, purchasing, quality management, expediting, shipping, receiving, warehousing, and issue (CII Phase- I Research 1983).

Integration of these functions usually requires some type of computerized system to achieve the level of coordination expected of the materials management process (Bell and Stukhart 1986).

> *When these functions are not properly managed individually and collectively, shortages and surpluses occur. More importantly, costly delays result when the required quantity or quality of materials are not on hand when needed (CII Phase I Research 1983).*

2.2.1 Materials Takeoff

Materials takeoff is identifying what materials are needed and how much. It can be executed initially from plot plans or flow sheets, and then it gets updated, as more definitive design information becomes available. Bell and Stukhart (1986) indicated that since industry-wide standard coding systems and specification for either bulk materials (standard pipe and fittings, electrical wires and conduits, etc.) or engineered materials (pumps, fabricated pipes and tanks) have not been established yet, they recommend the unification of existing coding systems established by individual designers (Bell and Stukhart 1986).

After the takeoff is completed, a consolidated bill of materials is created and entered in a computer system. Most computer systems are capable of tracking materials from requisitions, performing requisition sorts, and identifying material requirements.

2.2.2 Purchasing

One of the most important things to do after defining the project materials requirements is defining the purchasing responsibilities of the home office and field office. It is extremely important that the purchasing function be fully integrated into the overall materials management system (CII Cost and Benefits of Materials Management Systems 1986). It is also important to define the purchasing responsibilities of both the owner and the contractor. Hira indicated that Home office purchases allow close corporate control and take advantage of the saving possible through its buyer specialization, consolidations of various job requirements for informed pricing, and access to better sources. On-site purchasing is necessary in remote places or at times when waiting for home office purchasing will delay the progress of the project (Hira Successful Construction Cost Control).

Plemmons and Bell summarized the activities of purchasing as:

This concerns the establishment of forms and procedures to purchase materials; developing standard terms and conditions; issuing request for quotations (RFQ); evaluating bids; price and contract negotiation; preparing and administering purchase orders; and executing close out activities, including surplus disposal, addressing claims and backcharges, and records storage (Plemmons and Bell 1994).

2.2.3 Quality Management

Construction quality relies on accurate, clear statements of quality control requirements, arrived at by translating user needs into specifications and project quality plans and programs (CII Project Materials Management Planning Guide 1987).

It is widely recognized that the cost of failure is much higher than the cost of quality. CII studies indicated that quality is one of the most important, if not the most important, function of materials management (CII Project Materials Management Primer). Planning can avoid unpleasant surprises and delays due to quality breakdowns in the materials management system.

Several studies have shown that, although most of the non-conformances occur downstream, in fabrication or testing, the ultimate source of materials *management failure or success is planning (CII Project Materials Management Planning Guide 1987).*

2.2.4 *Expediting*

The primary goal of expediting is to insure that materials are delivered to the construction site on time. A previous study indicated that 28% of the craft-worker's time was idle or nonproductive due to unavailable materials and tools at time and place of need (Frederick 1991). Of the three types of expediting, proactive, reactive, and status reporting, the first (proactive) is considered the most productive yet the most labor intensive one. Under proactive expediting, the expediter initiates early vendor contact and maintains these contacts throughout the project, will see that engineering drawings are submitted on time, will check that critical materials are ordered in a timely manner, and will monitor delivery of sub-components or other critical operations (CII *Project Materials Management Planning Guide 1987).* Two approaches can be taken in deciding what type of expediting is most appropriate. The first approach is to choose one expediting type for the entire project. The second and probably the more appropriate approach is to use a combination of the three expediting methods where different materials require different expediting methods. For example, materials on the critical path will require proactive expediting, while other materials need only reactive expediting.

2.2.5 *Shipping*

The primary objective of transportation is to transport materials to the construction site in the most timely, most cost effective and safest manner possible in order to complement construction schedule requirements (CII *Project Materials Management Planning Guide 1987).*

Special consideration is required in setting terms. Free on board (F.O.B), the point at which ownership of material transfer to the buyer, is one of the terms required to be determined. CII studies indicated that significant savings are possible through the use of national agreements or negotiated project transportation agreement (CII Project Materials Management Primer).

2.2.6 *Receiving*

One of the many responsibilities of site office, is proper receiving of goods. CII studies indicated that a large percentage of the most costly materials-related problems occur after the materials have been delivered to the site (CII Cost and Benefits of Materials Management Systems 1986).

In order to ensure timely completion of a construction project, proper accounting for the receipt of materials is imperative (James 1991)

James listed six types that the materials management system should track:

- *Drop shipments from sub-tier suppliers,*
- *Number of pieces,*
- *Number of shipments,*
- *Shipment information,*
- *Receiving and handling information, and*
- *Parent item relationship if applicable (James 1991).*

Approximately 152,000 work-hours were saved on a $92 million project because materials were delivered directly to the site (Frederick 1991). The use of computers in generating receiving reports allows receiving personnel to quickly document the status of received materials.

2.2.7 *Warehousing*

Roger defined warehousing as the implementation of advanced techniques and technologies to optimize all functions throughout the warehouse (Roger 1994). By using proper warehousing management, four benefits could be gained:

- 15-30% increase in space utilization,
- Accurate retrievable data,
- Reduction of manpower, and
- Improved customer services (Roger 1994).

By contrast, poorly designed, crowded unmaintained lay-down areas will hinder movement of materials, increase labor costs and may even result in safety problems or construction claims (CII *Project Materials Management Planning Guide 1987).* Proper warehousing has a strong influence on the control of waste. Some equipment requires more protection than others. Ian specifies the factors influencing protection as:

- *Susceptibility to climate conditions,*
- *Value of materials,*
- *Size of units, and*
- *Scarcity of materials (Ian Materials Management on Building Sites).*

CII Publication specifies five storage levels:

- *Materials that require extraordinary protection (filtered, temperature, and humidity controlled environment). Examples of these types are plant, computers, relays, and printed circuit boards.*
- *Materials that do not require controlled temperature/humidity but do require indoor protection (weather tight, ventilated, 40° to 140°F). Examples of this type are transformers, motors, and flow nozzles.*

- *Materials that require moderate protection from the environment (indoor, not exposed to weather and dust). Examples of this kind are fuel oil pumps, tanks, and insulation.*
- *Materials that require minimal protection from the environment (outdoor on dunnage protected from standing-water). Examples of this type are cranes, re-bar, and cable and conduits.*
- *Materials which are practically insensitive to the environment. Examples of this type are precast concrete components, coal tar coated pipe, and railway equipment (CII Project Materials Management Planning Guide 1987).*

2.2.8 Issues of Materials

Issuing materials requires an accurate record about what, when and where material was used and who signed for it. This is usually accomplished by means of a warehouse requisition. The warehouse requisition should also provide a need by the requester to the materials and the specific purpose for which it will be used. Following a good issuing approach could help the issuing team in performing this task efficiently. A work package, by which all the material needed to perform a particular schedule activity is identified, is considered a very good approach (*CII Project Materials Management Planning Guide 1987).* Timely reverse issue of unused or surplus materials to the warehouse is necessary to minimize unnecessary buying of materials already available and to control certain items such as electrical cables.

2.3 Materials Management Measurement

In order to achieve customer satisfaction and increase profitability, some kind of measurement should be established for the construction projects. Being a result-oriented process, materials management is considered a good candidate for measurement.

> *Measurements are key to controlling, managing, and improving any work process. Without measurements, documenting and benchmarking the impact of intentional changes or improvements is limited (Plemmons and Bell 1994).*

The current conditions of materials management activities leave a lot to be desired. Research strongly suggests that materials management activities are not being practiced or are being practiced ineffectively in the construction industry (Frederick 1991). Since "what gets measured gets done", the need to provide process measures is imperative.

2.3.1 Process Measures

Harrington (1991) identified three process measures: efficiency, adaptability, and effectiveness. Efficiency is defined as the extent to which resources are minimized and waste eliminated in the pursuit of effectiveness. In connection with construction, the term efficiency is often limited to the utilization of equipment, fuel, materials, and tools. But labor productivity is a measure of efficiency and has long been an area of study and investigation within the construction industry (Plemmons 1995). Maloney notes that:

> *Many people operate with an extremely limited view of performance and consider the productivity of the firm's work force and the profitability of the firm as the only criteria of performance. An examination of the productivity provides a very narrow perspective on performance in a construction organization, while focusing on profitability does not ensure long-term survival of the firm. Profitability and productivity are necessary, but not sufficient, conditions for survival (Maloney 1990).*

Adaptability, as defined by Harrington, is the flexibility of a process to handle future, changing customer expectations and today's individual, special customer requests (Harrington 1991). The existence of change control procedures used by owner, engineer, contractor, and suppliers is one piece of evidence of adaptability (Plemmons 1995).

Effectiveness is having the right output at the right place, at the right time, at the right price (Plemmons 1995). Effectiveness encompasses the attainment of the organization's objectives (Maloney *1990)*. To ensure that a process is effective, the customer needs and expectations must be defined (Harrington 1991). There are two types of customers, internal customer and external customer. Both customers have to be satisfied. The next process customer in the materials management process is construction operations, namely those craft workers to whom materials are issued (Plemmons 1995).

2.3.2 Process Measurement Categories

Plemmons identified six attributes of performance for the materials management process. Five of them, quality, quantity, timeliness, cost, and availability, evolved from the Business Roundtable (BRT 1982) definition of materials management. The sixth one, accuracy, evolved from discussion with Construction Industry Action Group (CIAG) members (Plemmons 1995).

1. Accuracy: Is the degree to which an item of information is true or false (Plemmons 1995). It is an attribute of the information that "adds to relevant knowledge, reduces uncertainty and supports the decision-making process" (Senn 1990). Warehouse inventory accuracy is an example of accuracy.
2. Quality: Is the degree to which a system conforms to requirements, specifications, or expectations and is considered an outcome of an organizational system (Sink 1985). Plemmons and Bell have divided

quality into two subcategories - process quality and material quality:

> *Process quality is measured with regard to conformance to established process standards. Examples of process errors would include problems on shipping documentation, warehouse inventory accuracy, and problems with the withdrawal of material. Material quality is the category of effectiveness measures where the nonconformance is manifested in the materials and related to the materials management process. Examples of material quality would include the percentage of piping spool rework and job-site rejections of tagged equipment* (Plemmons and Bell 1994)

3. Quantity: Quantity measures evaluate the process flow or throughput in terms of volume or quantities related to planned accomplishment, for example, the average line items per release (Plemmons and Bell 1994). It is an attribute of the observable outputs that result from worker or work-group performance (Swanson 1994).
4. Timeliness: Is the measurable interval between two events or the period during which some activity occurs (Swanson 1994). Measures of this characteristic report duration aspects of the materials management process (Plemmons 1995). Materials withdrawal request (MWR) processing time is one example of timeliness.
5. Cost: Cost characteristics define the process in terms of meeting planned cost and labor targets (Plemmons 1995). Examples of cost effectiveness include the total surplus, average man-hour per PO, and construction time lost.
6. Availability: Availability measures the ability of the materials management process to fill requests for materials at the agreed time and place (Plemmons 1995). It is a major element of customer service (Firth

et al. 1988). Examples of this attribute include the percent of material availability, stockout analysis and backorders.

2.3.3 Key Effectiveness Measures

After identifying 35 effectiveness measures that either have been used in the past, are currently in use or have potential usage, Plemmons (1995) sent a survey to functional experts to identify which measures best communicate the effectiveness of the industrial construction materials management process. Plemmons then identified 12 key effectiveness measures that have a 25% or above response rate as to best communicate the effectiveness of materials management process for fixed-price contracts, with material availability as the primary measure. A further 11 key effectiveness measures for cost reimbursable contracts, were identified with construction time lost and material availability as the primary measures. Due to the low response received for unit price and guaranteed maximum price contractual arrangements, no evaluation concerning the proposed effectiveness measures were identified.

Two measures, piping spool rework (Q1) and commodity timeliness (T6) were not added to the lump sum contractual arrangement key effectiveness measures because they received only 17% response rates.

Similarly, three measures, materials receipt problem (AC1), bid/ evaluate/ commit lead-time (T2), and materials withdrawal request lead-time (T7) were not added to the cost reimbursable contractual arrangement because they received only an 8% response rate.

Table 2.1 shows a listing of the key effectiveness measures for the two types of contracts in a descending order according to their importance (Plemmons 1995):

Table 2.1 Key Effectiveness Measures

S/n	Fixed price contracts	Res-ponse rate	Cost reimbursable contracts	Res-ponse rate
1	Materials availability (AV1)	67%	Construction time lost (C5)	75%
2	Materials receipt problems (AC1)	33%	Materials availability (AV1)	67%
3	Jobsite rejections of tagged equipment (Q2)	33%	Procurement lead time (T1)	42%
4	Materials receiving processing time (T4)	33%	Commodity vendor timeliness (T5)	42%
5	Commodity vendor timeliness (T5)	33%	Materials receipt problems (AC1)	33%
6	Construction time lost (C5)	33%	PO to materials receipt duration (T3)	33%
7	Warehouse inventory accuracy (AC3)	25%	Warehouse inventory accuracy (AC3)	25%
8	Procurement lead time (T1)	25%	Piping spool rework (Q1)	25%
9	Bid/evaluate/commit lead time (T2)	25%	Jobsite rejections of tagged equipment (Q2)	25%
10	PO to material receipt duration (T3)	25%	Commodity timeliness (T6)	25%
11	Materials withdrawal request (MWR) lead time (T7)	25%	Total surplus (C11)	25%
12	Total surplus (C11)	25%		

2.3.4 Description of the Key Effectiveness Measures

Plemmons (1995) described the key effectiveness measures as the following:

1. *Materials availability (AV1):*

Measure: AV1 is calculated by dividing the total number of material line items issued by the total number of material line items requested.

Description: This measure represents the ability of the materials management process to issue or deliver properly scheduled and communicated material requirements to construction operations prior to what is commonly recognized as the activity early start date (ESD) or the field need date (FND).

AV1 is commonly associated with those materials and equipment items with need dates that have been established and updated on a regular basis.

Measure location: At the interface of the warehouse function with construction operations.

2. *Materials receipt problems (AC1):*

Measure: AC1 reports the data or information discrepancies associated with a material delivery that, if not detected and corrected, would cause inaccuracies in the project materials management database.

Description: material receipt problems occur when shipping documents or materials do not agree in specific areas with the purchase order or receiving report. The action of clarifying or correcting one error associated with an individual PO line item constitutes one discrepancy. Discrepancies may be identified on bills of lading, packing lists, POs, advance shipping notices (ASNs), and other material related documentation. This measure is the percentage of line items received without discrepancy.

Measure location: At the interface between the vendor and the warehouse function.

3. *Jobsite rejections of tagged equipment (Q2):*

Measure: Q2 represents the percentage of all rejections of tagged equipment. A rejection occurs when construction notifies the field control function of return of the item.

Description: the ability of the design and materials management processes to provide tagged equipment in accordance with requirements is critical to maintaining efficient construction operations. The measure accounts for the situation where the materials management process functions correctly to provide an item that cannot be used in its current form or configuration.

Measure location: At the interface between the construction operations and the field control function.

4. *Materials receiving processing time (T4):*

Measure: T4 reports the percentage of material received by the warehouse that is processed within two time periods, same day, and by next day.

Description: The processing time starts when a shipping document is time/date stamped by the warehouse receiving activity and a copy is returned to the transport carrier. The processing time ends when the material is updated to received status within the materials management system. The processing time encompasses a number of activities. These activities may include but not be limited to: receiving the delivery; inspecting the paperwork and the materials; determining the over, short, and damaged (OS&D) status; resolving spot overages and shortages; documenting damaged goods, adjusting the quantities by PO supplement; and updating the material status. The chronological determination of same day or next day is midnight (0000 hours). This measure may be used in conjunction with overtime cost and workhours of craft labor assigned to the warehouse.

Measure location: Within the warehouse and the field control functions.

5. *Commodity timeliness (T6):*

Measure: T6 is the percentage of deliveries made on or before the actual delivery date when compared to the required delivery date.

Description: The chronological determination of the same day or next day is midnight (0000 hours). This summary measure is reported as the percentage on time, but may represent two or more subcategories, for example one to three days late and three or more days late.

Measure location: At the interface of the vendors with the warehouse function.

6. *Construction time lost (C5):*

Measure: C5 is the percentage of construction time lost due to the impact of materials as estimated by construction supervisors.

Description: C5 reflects the direct impact of the materials management *process upon construction operations. The percentage of time lost due to materials is usually reported and collected using daily labor sheets. Feedback to the field control function is recommended on a weekly basis.*

Measure location: Between construction operations and the field control function.

7. *Warehouse inventory accuracy (AC3):*

Measure: AC3 measures process quality by reporting the accuracy of the information associated with the warehouse function.

Description: This measure is determined by comparing through a statistical sampling the data in the materials database with the physical assets in the warehouse and controlled laydown areas. The inventory results indicate the accuracy of the materials management database system when compared with the physical asset count. Any difference between the inventory records and the actual physical counts constitutes a discrepancy. These discrepancies may be investigated as to the root cause of the problem. Measure location: Is within the warehouse function.

8. *Procurement lead time (T1):*

Measure: T1 is the project ratio of the average procurement lead time in days and the planned procurement lead time. A suggested format is (19.5/21) to report average actual and planned values.

Description: Average procurement lead time is the average duration bounded by the transmission of the request for quotation (RFQ) until the receipt of a (signed) acceptance of the PO from the vendor. It may be composed of multiple commodity groups, which have been aggregated to provide the average values. The duration encompasses the RFQ, bid evaluation, negotiation and award, and issuance of the PO. The duration reflects the completeness of the RFQ information, the need for additional negotiation, delays, the efficiency of bid evaluation, the mechanism of issuing the PO and receiving the acceptance copy.

Measure location: At the interface between the vendor and the purchasing function.

9. *Bid/evaluate/commit lead time (T2):*

Measure: T2 is the average duration reported in days to bid, evaluate, and commit (BEC) to the purchase of materials. It uses a ratio format to communicate the average duration and the planned duration for example (17.8/21).

Description: The measure is bounded by the receipt of the vendor's response to the RFQ and the issuance of the PO. While it may include some degree of negotiation and clarification, the measure focuses on the sequence of activities within the control of the purchasing function. The average BEC duration may be segregated by material grouping (piping, steel, controls, etc.) or by discipline (civil, electrical, mechanical, etc.) or by process. Measures are taken at two locations.

Measure location: The first T2A is at the interface of the vendor with the purchasing function. The second measure T2B is taken at the interface of the purchasing function with the vendor.

10. *PO to materials receipts duration (T3):*

Measure: T3 is the average duration from the issuance of the PO until the receipt date of the material(s). It uses a ratio format to communicate the average duration and the planned duration for example (12.5/15).

Description: Average duration is calculated based on each PO line item. Therefore, the measure is the sum of the issuance-to-receipt duration divided by the total number of receipts.

Measure location: The first measure location T3A is at the interface of the purchasing function with the vendors, and the second location T3B is at the interface of the vendor with the warehouse function.

11. *Material withdrawal request (MWR) lead time (T7):*

Measure: T7 measures the lead time allowed for the issuance or delivery *of materials by reporting time that is the difference between the MWR date and the need or requested delivery date. The measure is reported as a ratio of the average MWR lead time and the planned MWR lead time, for example (2.2/3).*

Description: The action of requesting a withdrawal of materials initiates a series of actions within the warehouse and field control functions. Too short a leadtime could generate inefficiencies that may not be directly related. For example, quick responses to MWR could interrupt normal warehouse operations and result in increased overtime and loss-time accidents, the results of which may not be clearly definable until the next reporting cycle. The MWR date is the date and authorization which is issued to the warehouse to withdraw specific materials from inventory. The chronological determination of same day or next day is midnight (0000 hours). Normally, the materials are staged (palleted, "kitted", or made ready for pickup or delivery) for the issue of the particular work planned. The lead time indicates the ability of construction operations to request material as the work package start date approaches, and, thereby, minimize the amount of time craft workers wait for materials. Accountability is maintained as the withdrawals are issued to individuals in the warehouse or delivered to project material drop sites. The total number of MWRs may be segregated into three categories. The first category is same day, or MWR date issuance. This category normally reflects the percentage of quick responses or emergency situations where the warehouse function issues materials outside the normal staging procedures. The second category refers to MWR date plus two days (MWR+2). Two days are provided to allow the warehouse function to receive the MWR, schedule the withdrawal of materials and stage the materials from inventory, and issue them. Two days normally allows for performing these activities without incurring overtime or additional costs.

Materials location: At the interface of construction with the warehouse function.

12. *Total surplus (C11):*

Measure: C11 reports the percentage value of unused materials in relation to the total purchase cost of materials.

Description: The value of unused materials is determined before being coded for return (restocking) or disposition by third parties or facility operations and maintenance.

Measure location: Within the warehouse and field control functions.

13. *Commodity vendor timeliness (T5):*

Measure: T5 reports the percentage of vendor deliveries that were delivered on time with regard to the promised delivery date and the actual delivery date. Description: The chronological determination of same day or next day is midnight (0000 hours). This measure reports the percentage of on time deliveries, but may also represent several subcategories, for example one to three days late and three or more days late.

Measure location: At the interface of the vendors with the warehouse function.

14. *Piping spool rework (Q1)*

Measure: Q1 reports the total number of piping spools identified as requiring rework (field modification) divided by the total number of piping spools, multiplied by 100 to provide a percentage or ratio. Q1 may be reported as a cumulative and/or periodic measure.

Description: Q1 reports materials related process quality as a specific evaluation of design and supplier fabrication) performance. Piping spools constitute major and critical elements of some construction projects and rework may significantly impact construction productivity. The root cause of piping rework may relate to any number of sources. Examples of these sources may include design and fabrication accuracy, owner/contractor changes (i.e. modification), shipping constraints, or schedule acceleration. Root cause analysis *of piping spool rework isolates the source of the problem for management action. In the case of owner or contractor changes, evaluating piping spool rework provides feedback on the impact of earlier decisions. Target levels of piping spool rework may be selected during the planning process as a project success factor. Monitoring the piping spool rework may evaluate the ability of the design and materials management processes to react to design changes without impacting construction operations.*

Measure location: At the interface of construction with the field control function.

2.4 Materials Management Computer Systems (MMS)

One of the factors that have had major impact on materials management is the availability of computers (Al-Otaibi 1995). Communication is considered the single most important factor that contributes to successful project management (CII Cost and Benefits of Materials Management Systems 1986). A computer is a good tool for communication. In their research study titled Cost and Benefits of Materials Management Systems, Bell and Stukhart concluded that the benefits of a computer system should exceed system costs, even under the most conservative assumptions (Bell and Stukhart 1986).

CII studies indicate that an effective MMS will produce a minimum of 6% savings in craft labor cost, a reduction of bulk materials surplus from a range of 5 to 10% to 1 to 3% of bulk materials purchased, a reduction in materials management manpower, and a saving in cash flow (CII 1985).

Bell and Stukhart classified computer systems into two categories:

1. *Database systems that track the status of engineered equipment and critical items.* Engineered equipment is broadly defined as items with assigned numbers such that they can be uniquely referred to during the

entire life of the project. Examples of such equipment are pumps, heat exchanger and control valves.

2. *Comprehensive, integrated systems that address all materials management functions for both engineered equipment and bulk materials (Bell and Stukhart 1986).* Bulk materials are those items manufactured to industry standard, and purchased in quantity. These materials include pipes, fittings, and cables.

CII publications indicate that the integrated system that uses a common database is the most effective one because basic information can be entered into the computer history once and be available to all users. Thus, redundant input labor and computer expenses are eliminated (CII Project Materials Management Planning Guide 1987).

Any materials computer system should identify, track, report, and facilitate control of project material from quantity takeoff, through the material control, procurement, construction, and startup phases of the project (CII Project Materials Management Planning Guide 1987).

To be effective, computer systems should include the following:

- *Full integration of all materials management functions throughout the home office and project site, with emphasis on establishing capabilities that will produce project cost saving benefits.*
- *Line item reporting of purchase orders and requisitions.*
- *Sufficient flexibility to respond to various contractual arrangements, facility types, project sizes and locations, as well as a wide range of anticipated owner requirements and constraints.*
- *Online capability to ensure availability of current information to all system users.*

- *A menu driven screen format, or some other user friendly format, to ensure user acceptance and minimum user training time.*
- *Hardware portability, i.e., software that can be used on either small or large computer systems, depending on the project data requirements.*
- *Compatibility with other engineering, accounting, cost estimating, and projects control computer systems (CII Project Materials Management Primer 1988).*

Two inventory techniques, MRP (material requirement planning), and JIT (just in time) are used in the manufacturing and construction industry. An MRP system is more appropriate when demand is discontinuous, dependent, and nonuniform, but where demand is continuous and dependent, JIT is the suitable one (Al-Otaibi 1995). Thus MRP is more suitable for the construction environment, while JIT is more suitable for the manufacturing environment.

2.5 Benchmarking

The International Benchmarking Clearinghouse defines benchmarking as "the practice of being humble enough to admit that someone else is better at something and being wise enough to try to learn how to match and even surpass them at it" (IBC 1993). Xerox, a pioneer in benchmarking offers another definition of benchmarking as "the continuous process of measuring products, services, and practices against the toughest competitors or those recognized as industry leaders" (Rothman 1992).

Benchmarking offers a good tool for measurement and improvement. Benchmarking quantitative measures presents management with comparative information to justify new technologies and to measure the success or failure of implementation (James and Bell 1994). The use of benchmarking is increasing day by day due to the benefits realized by those companies who have already tried it. As of September 1991, 60 to 70% of the largest U.S. companies had established benchmarking programs (Biesada 1991).

The DOE (Department of Energy, US) benchmarking for cost improvement research concluded that 15- 25% savings can be expected on selected processes and activities if benchmarking is properly implemented and utilized (Pramod et al. 1994). Xerox, a winner of the prestigious Malcolm Baldridge National Quality Award, gained the following achievements through benchmarking:

- Inventory reduced by two-thirds.
- Engineering drawings doubled per person.
- Marketing productivity improved by one-third.
- Service labor cost reduced by 30%.
- Distribution productivity improved by 8-10% (Bendell et al. 1993).

According to Willborn and Cheng (1994), some of the lessons that result from benchmarking include:

- Stretch goals can be met.
- Both product and service quality must be improved.
- Not only does the company have to serve a customer, everyone in the company has to satisfy a customer internal in the company.
- Clear ownership of multifunctional processes must be assigned.
- Management and staff must realize how much work is required and which risks need to be taken.

Pramod et al. divided benchmarking into three types, competitive, functional, and internal benchmarking.

1. Competitive benchmarking:

   Is an approach that studies product designs, processes, capabilities, or administrative methods used by business competitor. To hide the identity of the inquiring firm, competitor benchmarking studies are often heavily reliant on secondary research and consulting firms. Copying a competitor can be a mistake if the practices chosen to copy are less than desirable.

2. Functional benchmarking:

   Are performed with non-competitors. The goal of functional benchmarking is to improve an organization's processes through implementing new process enablers rather than from learning a competitor's abilities. Benchmarking attempts to find, for any given function, the secrets of an industry leader's success.

3. Internal benchmarking:

   In many organizations, internal benchmarking is the most efficient method for finding and implementing improved process enablers. An internal benchmarking study attempts to find study partners within the same organization (Pramod et al. 1994).

Another type of benchmarking is generic, which is considered as an offshoot of the functional benchmarking. Camp identified it as "an application of functional benchmarking that compares a particular business function in two or more organizations" (Camp 1989).

Regardless of the type used, benchmarking consists of four primary steps. These steps are plan, collect, analyze, and improve, which closely resemble the four-step approach to quality management commonly known as the Deming cycle or the plan, do, check, and act (PDCA) cycle (Plemmons 1995). Below is a summary of these four steps:

- Plan: the plan step addresses the planning of a benchmarking project. Activities in this step include identifying the process to benchmark, understanding in detail the process flow and the process performance measure, and determining the data collection method.
- Collect: this involves those activities primarily associated with the collection of data. Beginning with the collection of process data within the company, the benchmarking team activities would include planning the external data collection procedures, gaining participation from the process owner and the benchmarking partners, collecting data, and possibly making on-site observations.
- Analyze: comparative data are analyzed for performance gaps and enablers. Enablers are those processes, practices, or methods that produce the "best-in-class" performance. Activities in this step include organizing the data to permit identification of performance gaps by comparing current performance against benchmarks, identifying the reason for these gaps, projecting performance three to five years into the future, isolating those enablers that correlate to process improvement, and determining the adaptability of the enablers to current processes.
- Improve: during this step, the applicable process enablers and best practices are integrated into company operations. The activities in this step include setting goals based on exceeding the performance gap, developing an action plan, committing resources and implementing the plan, monitoring and reporting progress toward the goal while regularly re-calibrating the benchmarks (Plemmons 1995).

Unlike the manufacturing industry, formal benchmarking activities are not widely applied within the construction industry (Lema and Price 1995). Lema and Price recommended conducting research to address the potential for benchmarking in the construction industry as a tool to:

- Identify and prioritize an area for performance improvement potentials.
- Identify sources of best performance and best practices.
- Set out a methodology for adopting and improving the best practices in an organization for quality and productivity improvement.
- Develop a framework for performance comparisons and target setting in an organization, within the industry and outside the industry; i.e., internal competitive and functional benchmarking (Lema and Price 1995).

After conducting a literature search, Fisher concluded that there are currently no available benchmarked standards for the construction industry, nor is there a nonprofit organization established for the purpose of collecting data and information in the industry for benchmarking, with the exception, he added, of the HBR (Houston Business Roundtable), which started to create benchmarking standards for the industry (Fisher et al. 1995). Early in 1992, a benchmark task force was created from members of the HBR to undertake the task of benchmarking construction industry activities. The team identified five tasks:

- Ascertain whether or not there is an interest in benchmarking among HBR member companies.
- Decide what activities to benchmark.
- Decide how to measure each activity.
- Collect information.
- Analyze information (Fisher et al. 1995).

After verifying an interest among HBR members, the team identified top 10 activities to be benchmarked:

1. Actual versus authorized costs
2. Schedule: actual versus estimated
3. Scope changes
4. Engineering rework
5. Construction labor: actual versus estimated
6. Field rework
7. Worker-hours per drawing
8. Project cost distribution
9. Field defects
10. Percent of rejected welds

Of the top 10 activities, the team chose to proceed with the four where they felt data was readily available. These four are: actual versus authorized cost; actual versus target schedule; actual versus estimated construction labor; and change orders versus original authorized cost (scope changes). 17 companies submitted data on 567 projects. After analyzing the data, the following initial conclusions were reached:

- A tendency to overestimate construction costs (an average actual cost versus original authorized cost ratio of 0.9)
- A community average for change orders of 11% of original authorized cost.
- A tendency to underestimate construction schedule (an average actual schedule versus original estimated schedule ratio of 1.08) (Fisher et al. 1995).

The risk to benchmarking is now being debated. Fisher, however, quoted an attorney: "The bigger risk is in not benchmarking. Benchmarking is such a powerful tool, you can not afford not to do it. There is nothing more powerful than for you to see for yourself how to do it better" (Scheffler and Powers 1992).

The trend toward benchmarking in the construction industry is increasing along with TQM. Some studies have led researchers to believe that companies must institute TQM or become noncompetitive in the national or international construction and engineering world within the next 5-10 years (Burati et al. 1991).

3. THE MODEL

The effectiveness-measuring model will be composed of three major parts, input, data processing, and output. Using an Excel spreadsheet, the model will only require simple formulas to be configured correctly.

Table 3.1 The Measuring Model

	MEASURING THE EFFECTIVENESS OF MATERIALS MANAGEMENT IN INDUSTRIAL PROJECTS		
	Type of the industrial project	**Type of contract**	
	Refinery ☐	Fixed Price (lump sum)	☐
	Petrochemic ☐	Cost reimbursable	☐
	Industrial plant ☐	Unit Price	☐
	Oil & Gas ☐	Guaranteed Max. Price	☐
	Water Desalination ☐		
	Duration in months	**Project value ($)**	
	1-12 ☐	<100,000,000	☐
	13-24 ☐	101,000,000-200,000,000	☐
	25-48 ☐	201,000,000- 300,000,000	☐
	>49 ☐	301,000,000-400,000,000	☐
		>401,000,000	☐
	% completion		
	<25% ☐		
	26-49% ☐		
	50-74% ☐		
	75-100% ☐		
	ACCURACY (AC)		
1	Materials receipt problem (AC1)	line items received without discrepancies(LIRND)	☐
	Fixed price only	line items received with discrepancies(LIRWD)	☐
		AC1= (LIRND/LIRND+LIRWD)*100	☐
2	Warehouse inventory accuracy (AC3)	no. of random items to be counted(ITC)	☐
	Both fixed price and cost reimbursable	no. of items found accurate(IFA)	☐
		AC3= (IFA/ITC)*100	☐
	AVAILABILITY (AV)		
3	Materials availability (AV1)	total number of line items issued (LII)	☐
	Both fixed price and cost reimbursable	Total number of line items requested (LIR)	☐
		AV1= (LII/LIR)*100	☐
	QUALITY (Q)		

4	Jobsite rejections of tagged equipment (Q2)	Number of tagged equipment (NTQ)	
	Both fixed price and cost reimbursable	Number of tagged equipment rejected (NTQR)	
		Q2= (NTQR/NTQ)*100	
5	Piping spool rework (Q1)	Number of piping spool (NPS)	
	Cost reimbursable only	Number of piping spool rejected(NPSR)	
		Q1=(NPSR/NPS)*100	
	TIMELINESS (T)		
6	Procurement lead time (T1)	Average actual procurement lead time (AALT)	
	Both fixed price and cost reimbursable	Average planned procurement lead time (APLT)	
		T1= [(AALT-APLT)/(APLT)]*100	
7	bid/evaluate/commit lead time (T2)	Average actual BEC lead time (ABECLT)	
	Fixed price only	Average planned BEC lead time (PBECLT)	
		T2= [(ABECLT-PBECLT)/(PBECLT)]*100	
8	PO to materials receipt duration (T3)	Average actual receipt duration (AMRD)	
	Both fixed price and cost reimbursable	Average planned receipt duration (PMRD)	
		T3= [(AMRD-PMRD)/(PMRD)]*100	
9	Materials receiving processing time (T4)	Average materials received in same day (MRSD)	
	Fixed price only	Average materials received in next day (MRND)	
		T4= [(MRSD-MRND)/(MRND)]*100	
10	Commodity vendor timeliness (T5)	no. of on time promised deliveries (OTPD)	
	Both fixed price and cost reimbursable	total no. of deliveries (TD)	
		T5= (OTPD/TD)*100	
11	Commodity timeliness (T6)	no of on or before required time deliveries(OTRD)	
	Cost reimbursable only	total no. of deliveries (TD)	
		T6= (OTRD/TD)*100	
12	Materials withdrawal request MWR lead-time(T7)	Average MWR lead-time (AMWR)	
	Fixed price only	Planned MWR lead-time (PMWR)	
		T7 =[(AMWR-OMWR)/(PMWR)]*100	
	COST (C)		
13	Construction time lost (C5)	Construction time lost (CTL)	
	Both fixed price and cost reimbursable	Construction time (CT)	
		C5= (CTL/CT)*100	
14	Total surplus (C11)	value of unused materials (VUM)	
	Both fixed price and cost reimbursable	value of total purchased materials (VTPM)	
		C11= (VUM/VTPM)*100	

The first part, the input, consists of the information required to calculate the key effectiveness measures (KEM). To calculate each KEM, several questions have to be searched for and thoroughly verified during the field study.

The second part of the model is data processing. The main function of this part is to process data obtained from the input part in an efficient manner. To do so, every KEM will be processed, and calculated separately for each project utilizing the configured Excel formulas. Special attention will be given to those KEM requiring subcategories, such as commodity timeliness measure (T6) that could have a one to three days late category and three to more days late category.

The calculation result of part two will be compiled in the output part for each project, listing the 12 KEM in descending order for the two major types of contracts, namely the fixed price contract and the cost reimbursable contract. The measures are divided into two groups. Group A represents those considered best when their values are as low as possible or measure the variance between actual and planned values. Group B represents those considered best when their values are as high as possible. Projects that have the lowest scores of group A and the highest scores of group B will be considered as having the most effective materials management system.

3.1 The Input

Depending on the type of contract, the data required to calculate the 12 KEM will be identified for each project prior to the field study, which will then be thoroughly looked for during the field study. The calculation formulas were mainly derived from suggestions made by Plemmons (1995) along with the key effectiveness measures. An exception was the formula used for calculating warehouse inventory accuracy (AC3), where the author utilized a formula commonly used in warehousing departments within manufacturing companies (Moore 1996). Plemmons had suggested a ratio format to record the measures. The author, however, utilized a percentage format instead, as this was found to be more convenient to use.

Below are several questions that have to be answered during the field study.

1. To calculate the materials availability measure (AV1), it is required to determine the total number of material line items issued and the total number of material line items requested.

AV1= (LII/LIR)*100, where:

LII= Total number of line items issued

LIR= Total number of line items requested

2. To calculate the materials receipt problems measure (AC1), it is required to determine the discrepancies associated with receiving materials and the total material line items received. Any deviation from the PO, either in the shipping documents or the materials received, is considered one discrepancy.

AC1=(LIRND/LIRND+LIRWD)*100, where

LIRND= line items received without discrepancies

LIRWD= line items received with discrepancies

3. To calculate the jobsite rejections of tagged equipment (Q2), it is required to determine the number of rejected tagged equipment and the total number of tagged equipment. A rejection occurs when an item is returned because the construction group considered it unfit in its current form.

Q2=(NTQR/NTQ)*100, where

NTQR= number of items of tagged equipment rejected

NTQ= number of items of tagged equipment

4. To calculate the materials receiving processing time measure (T4), it is required to determine the average receiving processing time of materials. To avoid confusion, It is essential to identify the processing time. The processing time encompasses a number of activities. These activities include receiving the delivery, inspecting the paperwork and the materials, determining the variance, documenting the damaged ones, and updating the material status.

T4= (MRSD-MRND)/MRND, where

MRSD= average amount of material received next day

MRND= average amount of material received in same day

5. To calculate the commodity vendor timeliness measure (T5), it is essential to determine the number of on time deliveries and the total number of deliveries. On time delivery should be defined; it could be established that materials received within two days are considered on time, while materials received after that are considered late deliveries.

T5= OTD/TD*100, where:

OTPD= number of on time deliveries

TD= total number of deliveries

6. To calculate warehouse inventory accuracy measure (AC3), it is essential to carry out statistical analysis in comparing the physical counts versus the system counts.

AC3= IFA/ITC)*100, where:

ITC= number of random items to be counted

IFA= number of items found accurate

7. To calculate the procurement lead-time measure (T1), it is essential to determine the average planned procurement lead-time and the actual average procurement lead-time.

T1= [(AALT-APLT)/(APLT)]*100, where:

AALT= average actual lead-time

APLT= average planned procurement lead-time

(AALT-APLT)= is an absolute number

8. To calculate the bid/evaluate/commit BEC lead-time measure (T2), it is required to determine the average planned BEC lead-time and the average actual BEC lead-time.

T2= [(ABECLT-PBECLT)/(PBECLT)]*100, where:

ABECLT= average actual BEC lead-time

PBECLT= average planned BEC lead-time

(ABECLT-PBECLT)= is an absolute value

9. To calculate the PO to materials receipt duration measure (T3), it is essential to determine average planned receipt duration and the average actual receipt duration.

T3= [(AMRD-PMRD)/(PMRD)]*100, where:

AMRD= average actual receipt duration

PMRD= average planned receipt duration

(AMRD-PMRD)= is an absolute value

10. To calculate the materials withdrawal request (MWR) lead-time measure (T7), it is essential to determine the average MWR lead-time and the average planned MWR lead-time. Some materials have different planned MWR lead-times.

T7= [(AMWR-PMWR)/(PMWR)]*100, where:

AMWR= average actual withdrawal request lead-time

PMWR= average planned withdrawal request lead-time

(AMWR-PMWR)= is an absolute value

11. To calculate the total surplus measure (C11), it is essential to determine the value of unused materials and the total value of purchased materials.

C11= (VUM/TPM)*100, where:

VUM= value of unused materials

TPM= total value of purchased materials

12. To calculate the construction time lost measure (C5), it is essential to determine the total amount of materials-caused lost time and the total amount of construction time.

C5= (CTL/CT)*100, where:

CTL= construction time lost

CT= construction time

13. To calculate the piping spool rework measure (Q1), it is essential to determine the number of piping spools identified as requiring rework and the total number of piping spools.

Q1= (NPSR/NPS)*100, where:

NPS= number of piping spools

NPSR= number of piping spools rejected

14. To calculate the commodity timeliness measure (T6), it is essential to determine the

T6= (OTRD/TD)*100, where:

OTRD= number of on time or before required time deliveries

TD= total number of deliveries

3.2 Data Processing

After collecting data from the field study, the data will be entered in the model for processing. Every project will then be processed separately, its key measures will be calculated using the built-in-the-model formulas and the information stored in an Excel format.

The sheets will be collated and results of every key measure will be put together for all projects and will be plotted after calculating their averages and standard deviations.

3.3 The Output

In order to be able to rank projects according to their performance, grouping the key effectiveness measures into two groups was deemed necessary. The key measures were put into two groups according to desired low and high values. Group A includes measures that are considered best when they are as low as possible.

Group A includes: jobsite rejections of tagged equipment (Q2); piping spool rework (Q1); procurement lead time (T1); bid/evaluate/commit lead time (T2); PO to materials receipt duration (T3); materials receiving processing time (T4); materials withdrawal request lead time (T7); construction time lost (C5); and total surplus (C11).

Group B includes measures that are considered best when they are as high as possible. Group B includes: materials receipt problem (AC1); warehouse inventory accuracy (AC3); materials availability (AV1); commodity vendor timeliness (T5); and commodity timeliness (T6).

Ranking the projects according to their performance will enable project management from comparing theirs with others and make benchmarking seem viable.

4. DATA COLLECTION

An initial search was made to identify ongoing industrial projects within Jubail Industrial City that were suitable for this study. Almost all industrial projects within the period from 1998 to 1999 in Jubail Industrial City were listed. Some projects were dropped temporarily, either they had not yet started or they were in their early stages, with insufficient data available. Saudi Aramco's industrial projects were targeted later due to the lengthy approval process expected to obtain permission to conduct such a study. The next step was to contact the project manager in every project. The author solicited SABIC's approval by first contacting technical representatives of SABIC's affiliates, who in turn agreed to cooperate and transfer the field study request with the relative data to their project managers. Each project manager was then contacted and asked to agree to have the study conducted on his project. Several visits were then made to meet various project management individuals as well as the prime contractors, with more attention being given to meeting materials managers.

Copies of the model were first sent to the project managers followed by site visits and meetings to discuss the requirements for the study and to reach a common understanding of the questions. Later visits were made to collect the required data and discuss the findings. On some occasions, further verification was required to confirm the accuracy of the data collected.

Regarding Saudi Aramco's projects, the author contacted the company's public affairs department to get their required approval. Official documents along with the model were sent to the company's Public Affairs Department by the Chairman of the Construction Engineering and Management Department. The author later made several follow ups both with Saudi Aramco's Public Affairs Department and the project design and construction department. After several months, the author received data concerning 9 projects. Only 7 projects had complete data, while 2 projects were not complete. The author tried to contact the concerned persons, but failed to solicit the missing data. Hence only 7 projects were included in this study.

During the field study all project data were kept confidential and a promise was made by the author to keep the name of the companies, the projects, and the involved parties anonymous.

In some projects where most of the procurement process took place in the contractor's headquarters offices, some questions were either faxed or emailed overseas to be filled out by the procurement group.

The data collection stage, in general, was a lengthy process and involved many follow up calls and visits. The whole process, however, was deemed necessary, worthwhile, and successful.

5. DATA ANALYSIS

A total of 17 projects, 9 belonging to SABIC affiliates in Jubail, 1 belonging to the private sector in Jubail, and 7 belonging to Saudi Aramco, have been measured from a materials management point of view. The overall responses were remarkably high. See Table 5.1

Table 5.1 Projects List

S/N	Project Type	Project Duration in Months	Project % Completion	Project Contract Type	Project Value in US$
1-	Industrial	25-48	75-100	Lump Sum	>401 M
2-	Petrochemical	1-12	26-49	Lump Sum	<100 M
3-	Petrochemical	25-48	50-74	Lump Sum	>401 M
4-	Petrochemical	13-24	75-100	Lump Sum	101-200 M
5-	Petrochemical	25-48	75-100	Lump Sum	101-200 M
6-	Petrochemical	25-48	75-100	Lump Sum	201-300 M
7-	Petrochemical	25-48	75-100	Lump Sum	301-400 M
8-	Petrochemical	25-48	50-74	Lump Sum	201-300 M
9-	Refinery	13-24	50-74	Lump Sum	<100 M
10-	Oil & Gas	25-48	75-100	Lump Sum	101-200 M
11-	Oil & Gas	25-48	50-74	Lump Sum	101-200 M
12-	Oil & Gas	13-24	75-100	Lump Sum	<100 M
13-	Oil & Gas	>49	75-100	Lump Sum	101-200 M
14-	Oil & Gas	13-24	75-100	Lump Sum	<100 M
15-	Oil & Gas	13-24	75-100	Lump Sum	<100 M
16	Oil & Gas	25-48	75-100	Lump Sum	<100 M
17	Petrochemical	13-24	26-49	Lump Sum	<100 M

As shown below in Table 5.2, 8 of the projects field studied were petrochemicals (47%), 7 were oil & gas (41%), 1 was a refinery, and 1 was an industrial project. Table 5.3 indicates that 9 of the projects had a duration period of 25-48 months (53%), 6 projects fell into the 13-24 month category (35%), while one fell into each of the over-48 month and under-13 month periods:

Table 5.2 Project: Type

Project Type	No. of Projects	Freq.
Industrial	1	5.88
Petrochemical	8	47.06
Refinery	1	5.88
Oil & Gas	7	41.18
Total	17	100.00

Table 5.3 Projects: Duration

Duration in Months	No. of Projects	Freq.
1-12	1	5.88
13-24	6	35.29
25-48	9	52.94
>49	1	5.88
TOTAL	17	100.00

For the percentage completion, 65% were 75-100% complete, (11 projects), 24% were 50-74% complete (4 projects), 12% of the projects were 26-49% complete (2 projects) and 0 project was <25% complete. See Table 5.4

All of the projects were contracted under the lump sum type of contract. See Table 5.5.

Table 5.4 Project: % Completion

% Completion	No. of Projects	Freq.
<26	0	0.00
26-49	2	11.76
50-74	4	23.53
75-100	11	64.71
Total	17	100.00

Table 5.5 Project: Type of Contract

Type of Contract	No. of Projects	Freq.
Lump Sump	17	100
Cost Reimbursable	0	0
Total	17	100

As far as the value of the project is concern, 7 of the projects were valued at less than US$ 100 million (41%) (7 projects). 5 projects were valued between $101-200 million (29%), 11.76 % of the projects had project value between 201-300 million US dollars and the same percentage for project value more than 400 million US dollars-2 projects. Only one project had project value range between 301-400 million US dollars. See Table 5.6

Table 5.6 Projects Value

Project Value In US$	No. of Projects	Freq.
≤100 m	7	41.18
101-200 m	5	29.41
201-300 m	2	11.76
301-400 m	1	5.88
>400 m	2	11.76
TOTAL	17	100.00

As mentioned before, the key effectiveness measures were divided into two groups, A and B. Group A represents measures that are considered best when they are as low as possible. Group B represents measures that are considered best when they are as high as possible.

Only measures that are related to the lump sum type of contract are discussed here due to the fact that there was no project with a cost reimbursable type of contract.

As shown in Table 5.7 and Table 5.8, the 12 key measures for each project were calculated. Table 5.7 shows the results of the calculation from project number 1 to project number 9, while Table 5.8 shows the results of the calculation from project 10 to project 17. The first column of both tables represents the key measure number, while the second column represents the description of the key measures along with the group number. The remaining columns list the project numbers from 1 to 9 and from 10 to 17 in Table 5.7, and Table 5.8 respectively. The bracketed numbers represent those with negative values. They were, however, considered as absolute values.

The values of some key measures were not available for some projects and therefore were left empty. Project number 7 in particular had half of the measures empty, all group B measures and 2 of group A measures, because they failed to cooperate.

Table 5.7 Project Measures 1-9

	Key measurements	Project Number								
		1	2	3	4	5	6	7	8	9
1	Material receipt problem (AC1) B	97.98	99.53	99.87	99.04	98.65	99.07	X	99.00	99.80
2	Warehouse inventory accuracy (AC3) B	90.00	X	100.00	85.00	95.00	95.00	X	80.00	X
3	Materials availability (AV1) B	95.00	95.20	100.00	98.40	100.00	99.40	X	94.80	95.00
4	Commodity vendor timeliness (T5) B	85.00	90.90	X	93.75	50.00	94.96	X	80.00	31.25
5	Jobsite rejections of tagged equipment (Q2) A	0.10	1.67	0.00	0.06	3.25	21.34	X	0.00	5.00
6	Procurement lead time (T1) A	100.00	0.00	8.00	200.00	25.00	(28.87)	15.38	14.00	0.00
7	bid/evaluate/commit lead time (T2) A	100.00	0.00	33.00	X	25.00	0.00	15.40	0.00	0.00
8	PO to materials receipt duration (T3) A	22.00	33.00	0.00	100.00	0.00	(5.00)	21.70	40.00	0.00
9	Materials receiving processing time (T4) A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	Materials withdrawal request lead-time(T7) A	0.00	(50.00)	0.00	(50.00)	0.00	0.00	X	100.00	(20.00)
11	Construction time lost (C5) A	14.29	8.33	0.00	X	X	X	2.20	4.17	X
12	total surplus (C11) A	0.10	0.02	X	1.50	2.14	1.08	5.00	X	0.00
	Group A Average	29.56	11.63	5.86	58.59	7.91	8.04	9.95	22.60	3.57
	Group B Average	91.99	95.21	99.96	94.05	85.91	97.11	X	88.45	75.35

Table 5.8 Project Measures 10-17

	Key Measurements	Project Number							
		10	11	12	13	14	15	16	17
1	Material receipt problem (AC1) B	80.00	100.00	97.57	98.58	98.76	100.00	87.67	96.97
2	Warehouse inventory accuracy (AC3) B	100.00	85.00	X	X	X	95.00	98.68	X
3	Materials availability (AV1) B	100.00	98.50	93.60	93.90	88.00	87.50	86.33	X
4	Commodity vendor timeliness (T5) B	70.00	87.50	89.80	19.93	100.00	78.26	X	13.54
5	Jobsite rejections of tagged equipment (Q2) A	0.00	0.00	0.00	26.67	2.56	4.86	0.00	2.97
6	Procurement lead time (T1) A	(20.00)	0.00	(20.00)	25.00	(34.00)	25.00	14.28	(20.57)
7	bid/evaluate/commit lead time (T2) A	(15.00)	0.00	(14.30)	25.00	50.00	20.00	33.33	14.28
8	PO to materials receipt duration (T3) A	(10.00)	0.00	(16.70)	16.70	(20.00)	33.00	33.33	39.62
9	Materials receiving processing time (T4) A	X	0.00	0.00	X	0.00	X	(33.33)	0.00
10	Materials withdrawal request lead-time(T7) A	X	0.00	50.00	0.00	(20.00)	0.00	X	(50.00)
11	Construction time lost (C5) A	0.00	0.00	0.00	X	33.30	0.00	X	X
12	total surplus (C11) A	0.07	0.00	0.40	0.03	4.00	0.50	X	X
	Group A Average	7.51	0	12.68	15.57	20.48	11.91	22.85	21.24
	Group B Average	87.50	92.75	93.66	70.80	95.59	90.19	90.89	55.26

Note: the numbers in parenthesis represent negative values, and X represents a missing value.

Since the key measures were divided into two groups, every project had two averages, one for Group A and another one for Group B measures. A detailed analysis for each project will be provided later in this paper.

Table 5.9 summarizes the results of the 12 key measures for all projects.

Table 5.9 Projects Summary Result

S/n	Key Measures	Weight	No. of projects	Average	Std. Deviation	The highest	The lowest
1	Materials receipt problem (AC1)	33%	16	97.03	5.41	100	80
2	Warehouse inventory accuracy (AC3)	25%	10	92.37	7.03	100	80
3	Materials availability (AV1)	67%	15	95.04	4.64	100	86.33
4	Commodity vendor timeliness (T5)	33%	14	70.35	29.37	100	13.54
5	Jobsite rejection of tagged equipment (Q2)	33%	16	4.28	7.96	26.67	0
6	Procurement lead-time (T1)	25%	17	32.34	48.73	200	0
7	Bid/evaluate/commit lead-time (T2)	25%	16	21.58	25.52	100	0
8	PO to materials receipt duration (T3)	25%	17	23.00	24.37	200	0
9	Materials receiving processing time (T4)	33%	14	2.38	8.91	33.33	0
10	Materials withdrawal request lead-time (T7)	25%	14	24.29	31.06	100	0
11	Construction time lost (C5)	33%	10	6.23	10.63	33.33	0
12	Total surplus (C11)	25%	13	1.14	1.65	5	0

The first column in Table 5.9 represents the key measure number, while the second column lists the description of the 12 key measures. The third column represents the weight or the response rate of the key measures as identified by Plemmons. The fourth column, titled "No. of projects", represents the number of responded projects to the particular key measure. The fifth and the sixth columns represent the average and the standard deviation respectively for each key measure. Finally the seventh and the eight columns list the highest and the lowest value respectively for each key measure.

5.1 Group B Measures

Group B measures represent those key measures that are considered best when they are as high as possible. Below is a discussion of those measures.

5.1.1 Materials Receipt Problem (AC1)

On calculating the materials receipt problem (AC1), the following formula was used:

AC1= [(LIRND/LIRWD)+(LIRWD)]*100, where:

LIRND= line items received without discrepancies

LIRWD= line items received with discrepancies

The formula here calculated the complement of the materials receipt problem. It represents the accuracy of the materials receipt measure. The higher the accuracy, the less serious the problem the warehouse team faced during the receiving stage.

The materials receipt problem (AC1) measure, which weighs 33%, was found to average 97%, based on respondents from 16 projects. Projects number 11 and 15 scored the highest, 100%, while project number 10 scored the lowest, 80%. The standard deviation was found to be 5.41%. This means that the accuracy of the received materials was near to perfect, as only 3% of received materials had discrepancies.

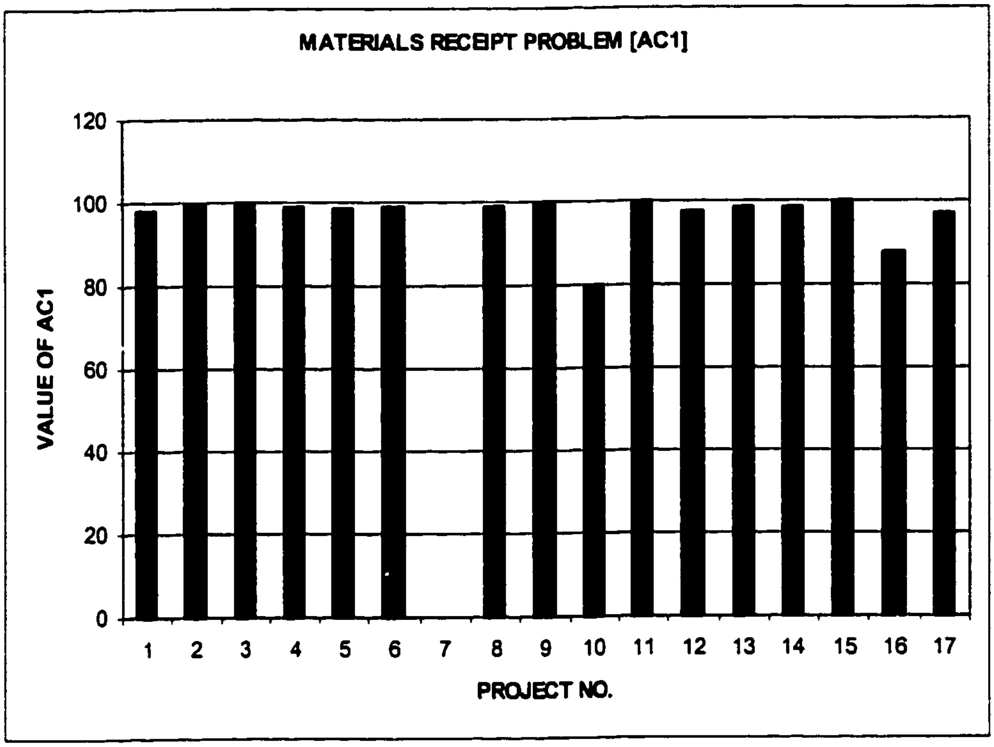


Figure 5.1 Materials Receipt Problem (AC1)

Table 5.10 Materials Receipt Problem (AC1)

Project No.	Material Receipt Problem (AC1) B
1	97.98
2	99.53
3	99.87
4	99.04
5	98.65
6	99.07
7	*X*
8	99.00
9	99.80
10	80.00
11	100.00
12	97.57
13	98.58
14	98.76
15	100.00
16	87.67
17	96.97
Average	97.03
Std. Dev.	5.41

Note: X represents a missing value

5.1.2 Warehouse Inventory Accuracy (AC3)

On calculating warehouse inventory accuracy (AC3), the following formula was used:

AC3= (IFA/ITC)*100, where:

ITC= number of random items to be counted

IFA= number of items found accurate

Warehouse inventory accuracy (AC3) measure, which weighs 25%, was found to have an average of 92.37% based on 10 respondents. This means that 92.37% of the items physically counted were found accurate, equal the system or book count. Two projects number 3 and 10 scored the highest, 100%, while one project number 8 scored the lowest 80%. Inventory accuracy measure was not calculated for a number of projects because it was asked late in the data collection stage and some of the projects were either completed or it was difficult to recommunicate with the concerned people for practical reasons beyond the ability of the author. The standard deviation was found to be 7.03. The desired warehouse inventory accuracy is 95%.

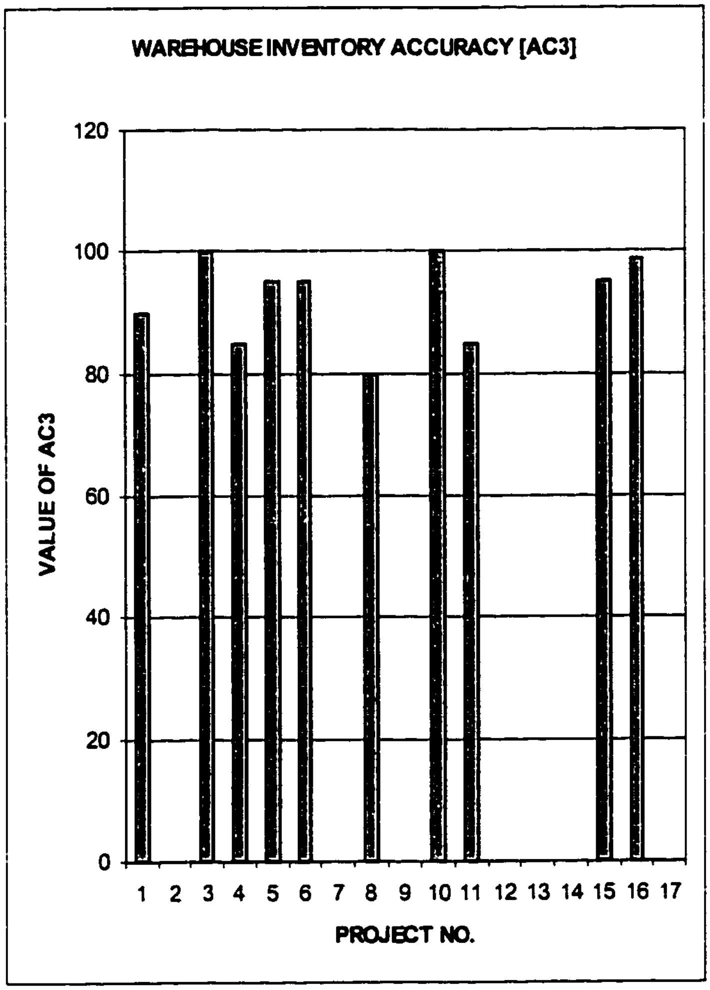


Figure 5.2 Warehouse Inventory Accuracy (AC3)

Table 5.11 Warehouse Inventory Accuracy (AC3)

Project No.	Warehouse Inventory Accuracy (AC3) B
1	90.00
2	X
3	100.00
4	85.00
5	95.00
6	95.00
7	X
8	80.00
9	X
10	100.00
11	85.00
12	X
13	X
14	X
15	95.00
16	98.68
17	X
Average	92.37
Std. Dev.	7.03

Note: X represents a missing value

5.1.3 Materials Availability (AV1)

On calculating the materials availability measure (AV1), the following formula was used:

AV1= (LII/LIR)*100, where:

LII= Total number of line items issued

LIR= Total number of line items requested

It was found that materials availability (AV1), which is the most important and heavily weighted measure (67%), had an average of 95% based on respondents from 15 projects. Three projects (3, 5 and 10) scored the highest, 100%, while project number 16 scored the lowest, 86%. The rest of the projects, 11 projects scored between 88 and 100. The standard deviation was found to be 4.79. The high percentage indicates a well managed materials process, 95% of the materials requested by the construction group were found available and issued.

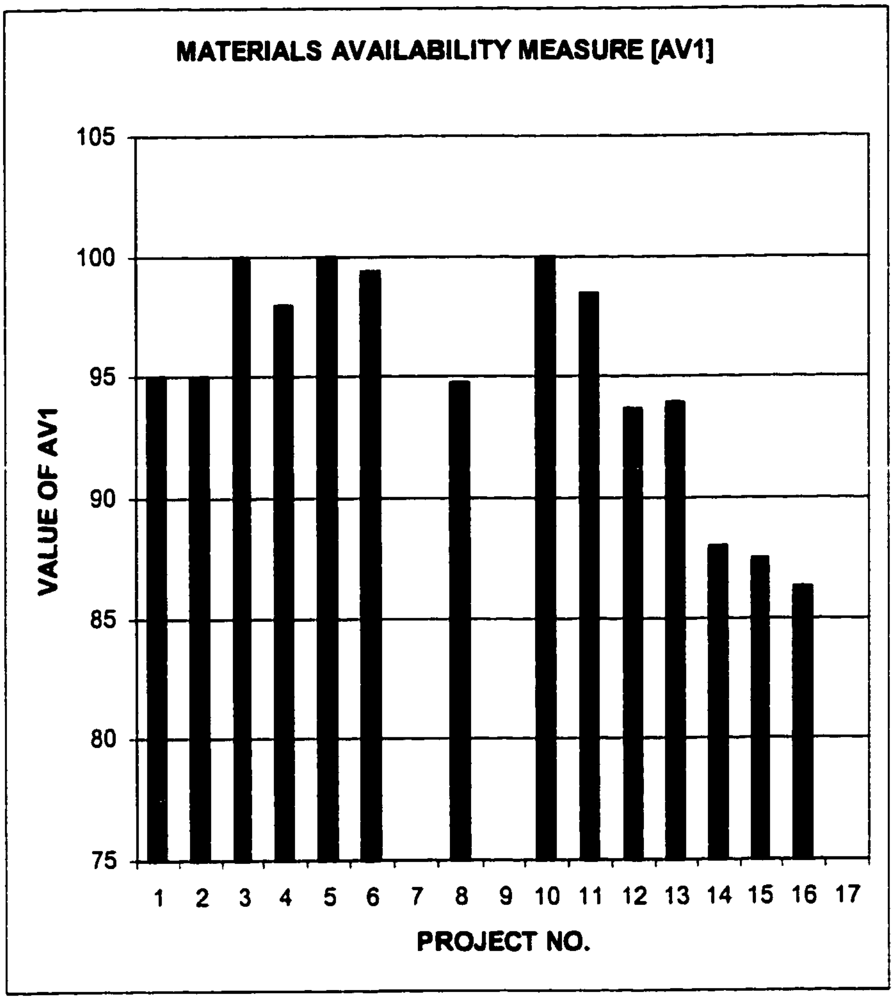


Figure 5.3 Materials Availability (AV1)

Table 5.12 Materials Availability (AV1)

Project no.	Materials Availability (AV1) B
1	95.00
2	95.20
3	100.00
4	98.40
5	100.00
6	99.40
7	*X*
8	94.80
9	95.00
10	100.00
11	98.50
12	93.60
13	93.90
14	88.00
15	87.50
16	86.33
17	*X*
Average	95.04
Std. Dev.	4.64

Note: X represents a missing value

5.1.4 Commodity Vendor Timeliness (T5)

On calculating commodity vendor timeliness, the following formula was used:

T5= (OTPD/TD)*100, where:

OTPD= number of on time promised deliveries

TD= total number of deliveries

On calculating commodity vendor timeliness (T5) measure, which weighs 33%, it was found that an average of 70.35% of deliveries were considered on time, while 29.65% of deliveries were considered late based on 14 respondents. Project number 14 scored the perfect score while project number 17 scored the lowest (13.54%). The standard deviation was found to be 29.37. The relatively low average supports the idea that just on time policy (JIT) is not suitable in an environment where manufacturing of materials is far away from the construction sites, in this case overseas. According to an experienced project engineer, 65% of materials were procured overseas, which explains the late arrivals of some materials due to delay in custom clearance and statutory issues.

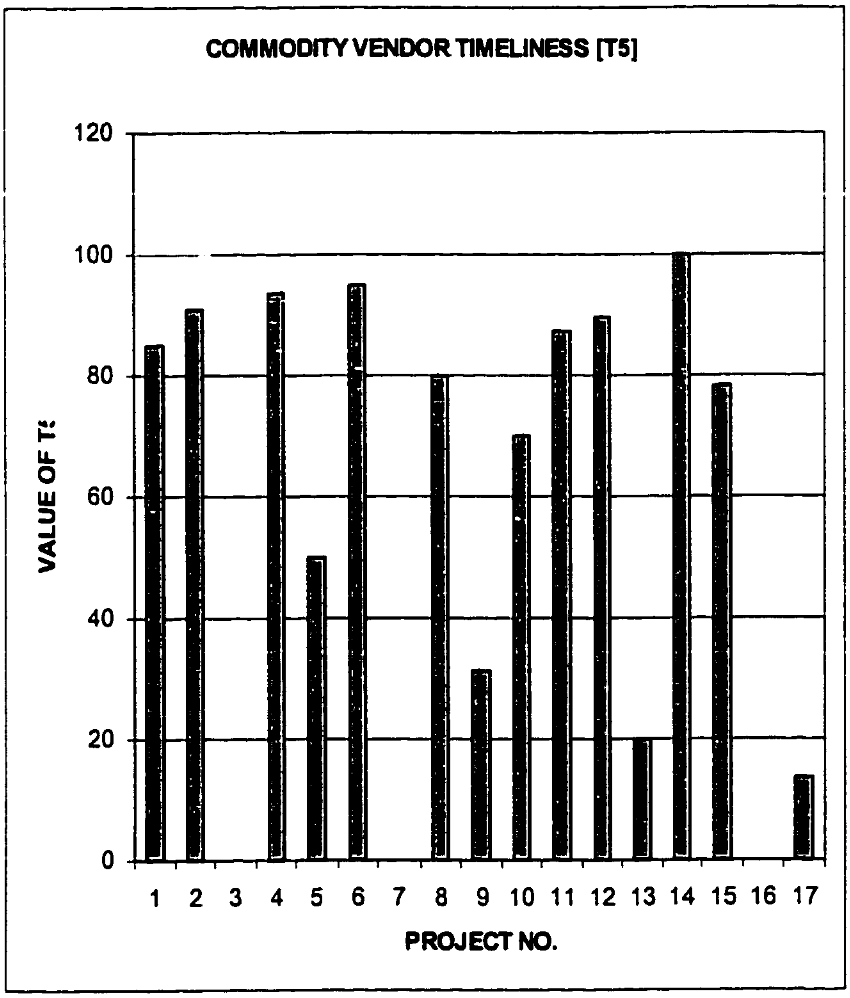


Figure 5.4 Commodity Vendor Timeliness (T5)

Table 5.13 Commodity Vendor Timeliness (T5)

Project No.	Commodity Vendor Timeliness (T5) B
1	85.00
2	90.90
3	X
4	93.75
5	50.00
6	94.96
7	X
8	80.00
9	31.25
10	70.00
11	87.50
12	89.80
13	19.93
14	100.00
15	78.26
16	X
17	13.54
Average	70.35
Std. Dev.	29.37

Note: X represents a missing value

5.2 Group A Measures

Group A measures represent those with desired values as low as possible. A total of seven measures is considered within group A. Below is a discussion of those measures.

5.2.1 Jobsite Rejection of Tagged Equipment (Q2)

On calculating jobsite rejection of tagged equipment Q2, the following formula was used:

Q2= (NTQR/NTQ)*100, where

NTQR= number of items of tagged equipment rejected

NTQ= number of tagged equipment

The average jobsite rejection of tagged equipment (Q2) measure which weighs 33%, was found to be 4.28% based on 16 respondents. The best value, zero value was recorded on 6 projects, projects number 3,8,10,11, 12 and 16. This means that the rate rejection for tagged equipment was zero on these projects. While the highest value, the least desired in this case, was found to be 26.67, for project number 13. Jobsite rejection of tagged equipment gives an indication of quality record with regard to materials management. The standard deviation was found to be 7.96.

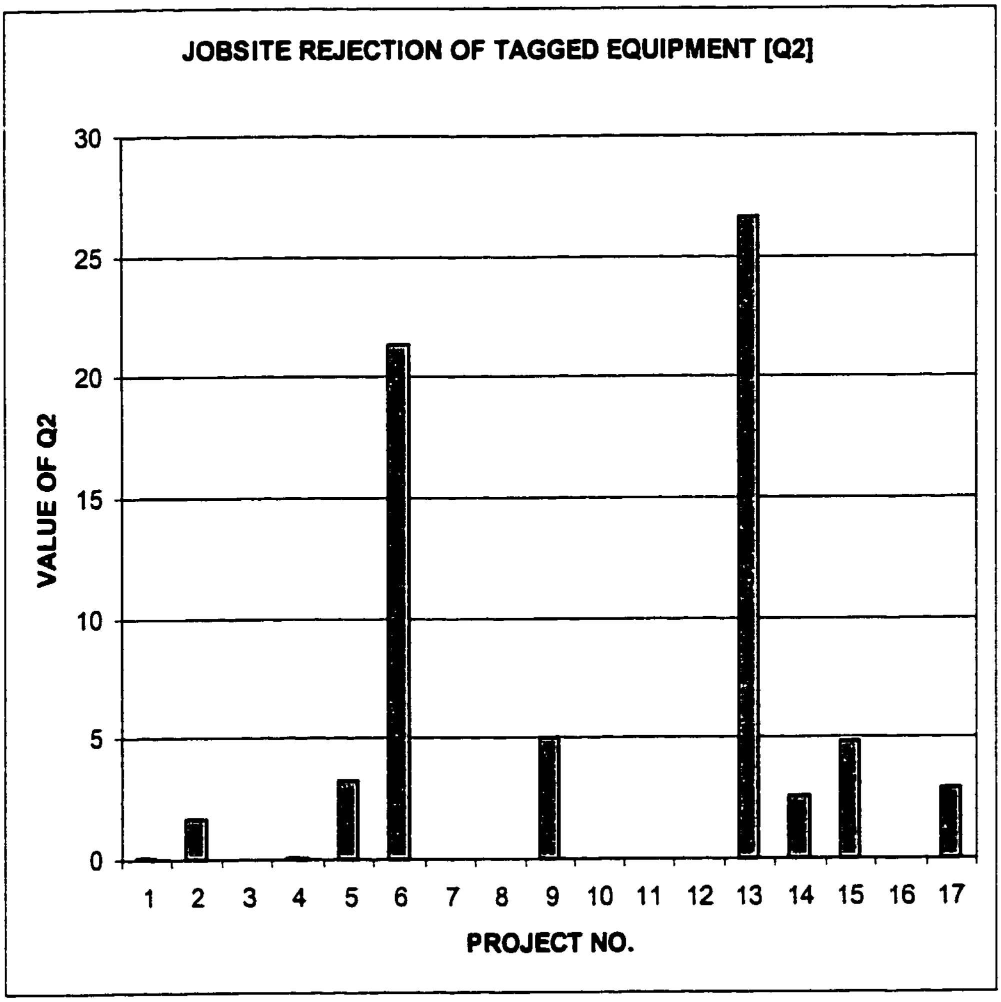


Figure 5.5 Jobsite Rejection of Tagged Equipment (Q2)

Table 5.14 Jobsite Rejection of Tagged Equipment (Q2)

Project No.	Jobsite Rejections of Tagged Equipment (Q2) A
1	0.10
2	1.67
3	0.00
4	0.06
5	3.25
6	21.34
7	X
8	0.00
9	5.00
10	0.00
11	0.00
12	0.00
13	26.67
14	2.56
15	4.86
16	0.00
17	2.97
Average	4.28
Std. Dev.	7.96

Note: X represents a missing value

5.2.2 Procurement Lead-Time (T1)

On calculating procurement lead-time (T1), the following formula was used:

T1= [(AALT-APLT)/(APLT)]*100, where:

AALT= average actual lead-time

APLT= average planned procurement lead-time

(AALT-APLT)= is an absolute value

On calculating the procurement lead-time (T1) measure, which weighs 25%, it was found to average 32.36, based on 17 respondents. The standard deviation was found to be 48.73. The lowest value was found to be 0 for project number 14, while the highest value was found to be 200, for project number 4. The relatively high standard deviation indicates the big variance between the average actual and the planned procurement lead-time for the studied projects.

One major contributor to this variance is that some equipment had a longer procurement lead-time than anticipated.

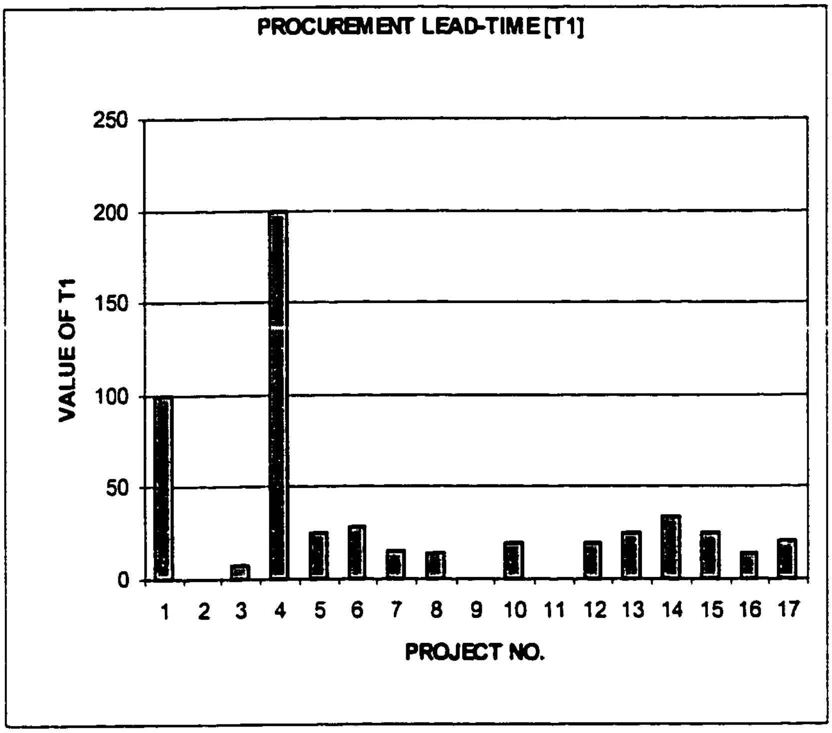


Figure 5.6 Procurement Lead-Time (T1)

Table 5.15 Procurement Lead-Time (T1)

Project No.	Procurement Lead Time(T1)
1	100
2	0
3	8
4	200
5	25
6	(28.57)
7	15.38
8	14
9	0
10	(20)
11	0
12	(20)
13	25
14	(34)
15	25
16	14.28
17	(20.57)
Average	32.34
Std. Dev.	48.73

5.2.3 *Bid/Evaluate/Commit Lead-Time (T2)*

On calculating bid/evaluate/commit lead-time (T2), the following formula was used

T2= [(ABECLT-PBECLT)/(PBECLT)]*100, where:

ABECLT= average actual BEC lead-time

PBECLT= average planned BEC lead-time

(ABECLT-PBECLT)= is an absolute value

On calculating the bid/ evaluate/ commit lead-time (T2) measure, which weighs 25%, it was found to average 21.58%, with 25.52 standard deviation. The lowest value was 0 and found in five projects, number 2,6, 8, 9, and 11, while the highest value was found to be 100 and recorded on one project, number 1. Two projects had negative values, 15 and 14.30 for projects number 10 and 12 respectively. This means that it took them less time than planned to bid/evaluate/ commit. Any big deviation from the planned lead-time is not desirable. It could reflect poor planning or the fact that the procurement staff may have worked some overtime hours. Both conditions are undesirable.

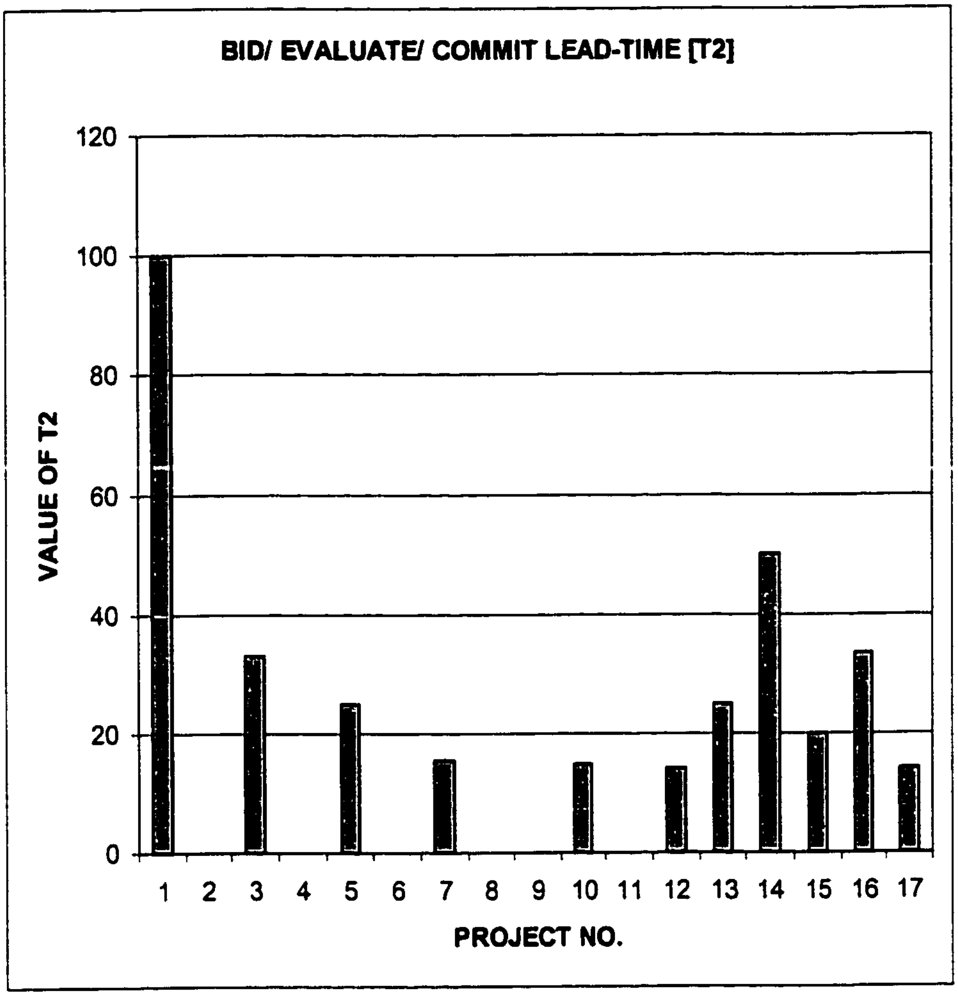


Figure 5.7 Bid/ Evaluate/ Commit Lead-Time (T2)

Table 5.16 Bid/Evaluate/Commit Lead-Time (T2)

Project No.	Bid/Evaluate/Commit Lead Time(T2) A
1	100
2	0
3	33
4	X
5	25
6	0
7	15.4
8	0
9	0
10	15
11	0
12	14.3
13	25
14	50
15	20
16	33.33
17	14.28
Average	21.58
Std. Dev.	25.52

Note: X represents a missing value

5.2.4 PO To Materials Receipt Duration (T3)

On calculating PO to materials receipt duration (T3), the following formula was used:

T3= [(AMRD-PMRD)/(PMRD)]*100, where:

AMRD= average actual receipt duration

PMRD= average planned receipt duration

(AMRD-PMRD)= is an absolute value

On calculating the above measure, which weighs 25%, it was found to average 23%, with 24.37 standard deviation. The lowest value was recorded on projects number 3, 5, 9, and 11, with a value of 0, while the highest value was recorded to project number 4, with a value of 100. Since this measure records the variance between the actual and the planned receipt duration form and the commencement of issuance of PO to the arrival of the desired materials, it indicated the difficulty in accurately estimating the arrival time. This measure and the two former ones, T1 and T2, reflect the importance of the procurement function during the materials management process. Four projects, number 6, 10, 12, and 14, had negative values, as their materials arrived before the planned arrival time. The arrival of unplanned materials could create serious problems in storing the materials as well as in providing the required cash flow. The other condition, the late arrival of materials, is also not desirable because it may lead to some lost construction time and may delay the completion of the project.

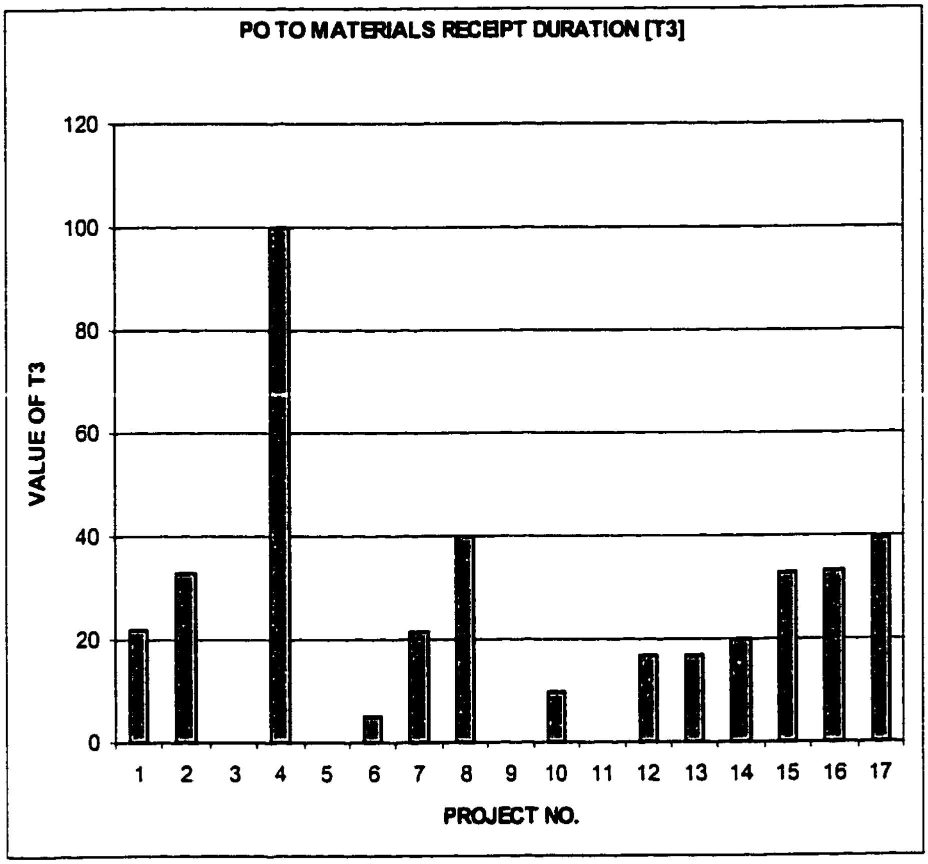


Figure 5.8 PO to Materials Receipt Duration (T3)

Table 5.17 PO to Materials Receipt Duration (T3)

Project No.	PO to Materials Receipt Duration(T3)
1	22
2	33
3	0
4	100
5	0
6	(5)
7	21.7
8	40
9	0
10	(10)
11	0
12	(16.7)
13	17
14	(20)
15	33
16	33.33
17	39.62
Average	20.97
Std. Dev.	24.36

5.2.5 Materials Receiving Processing Time (T4)

On calculating materials receiving processing time (T4), the following formula was used:

T4= [(MRSD-MRND)/(MRND)]*100, where:

MRSD= average quantity of materials received next day

MRND= average materials received in same day

(MRSD-MRND)= is an absolute value

On calculating this measure, which weighs 33%, it was found to average 2.38, with 8.91 standard deviation. All projects scored the same, except project number 16. This measure could be considered neutral, with materials processed on the same day equaling materials processed on the next day. Hence it may not be considered a timeliness measure to the industrial projects here.

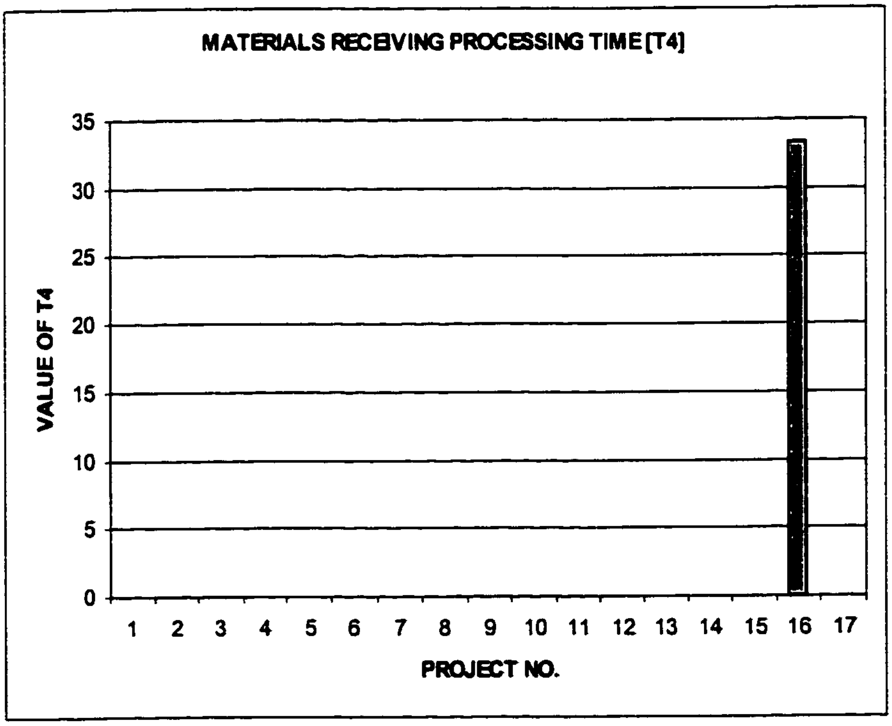


Figure 5.9 Materials Receiving Processing Time (T4)

Table 5.18 Materials Receiving Processing Time (T4)

Project No.	Materials Receiving Processing Time(T4)
1	0
2	0
3	0
4	0
5	0
6	0
7	0
8	0
9	0
10	X
11	0
12	0
13	X
14	0
15	X
16	(33.33)
17	0
Average	2.38
Std. Dev.	8.91

Note: X represents a missing value

5.2.6 Materials Withdrawn Request Lead-Time (T7)

On calculating the materials withdrawal request lead-time (T7), the following formula was used:

T7= [(AMWR-PMWR)/(PMWR)]*100, where:

AMWR= average actual withdrawal request lead-time

PMWR= average planned withdrawal request lead-time

(AMWR-PMWR)= is an absolute value

On calculating this measure, which weighs 25%, the average was found to be 24.29% with 31.06 as a standard deviation. Seven projects, numbers 1,3,5,6,11, 13, and 15, scored the lowest value, 0, which means the actual matches the planned withdrawal lead-time for these projects, while project number 8 scored the highest, 100.

Five projects, numbers 2, 4, 9, 14, and 17, had negative values for this measure, which means that it took them less time to process the withdrawal of materials than anticipated or asked for. All of the projects asked for two days to process materials withdrawal from warehouse, which seems a reasonable time. This indicates that the warehouse sections were probably well staffed or that materials flow was very smooth. This measure did not seem to accurately reflect the effectiveness of the materials management process.

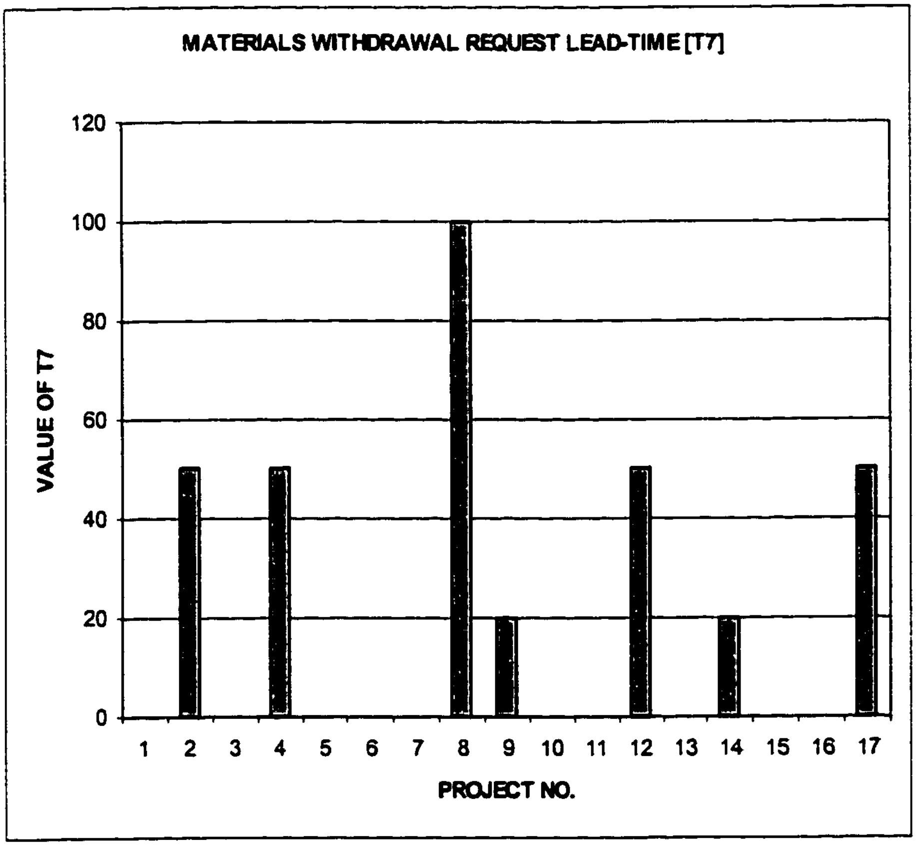


Figure 5.10 Materials Withdrawal Request Lead-Time (T7)

Table 5.19 Materials Withdrawal Request Lead-Time (T7)

Project No.	Materials Withdrawal Request MWR Lead-time(T7)
1	0
2	(50)
3	0
4	(50)
5	0
6	0
7	X
8	100
9	(20)
10	X
11	0
12	50
13	0
14	(20)
15	0
16	X
17	(50.00)
Average	24.29
Std. Dev.	31.06

Note: X represents a missing value

5.2.7 Construction Time Lost (C5)

On calculating construction time lost (C5), the following formula was used:

C5= (CTL/CT), where:

CTL= construction time lost

CT= construction time

On calculating the construction time lost (C5) measure, which weighs 33%, the average was found to be 6.23% based on 10 respondents, with 10.63 as a standard deviation. Five projects (numbers 3, 10, 11, 12, and 15) had zero construction time lost due to unavailability of materials. The highest construction time lost was recorded in project number 14, which experienced construction time lost of 33.33%. The same project that scored almost the lowest in materials availability measured 88%. This clearly indicates the effect of materials availability on the construction time. The response level to this measure is considered low, which indicates either lack of feedback from the construction group or a relatively low labor cost. The latter is more reasonable here.

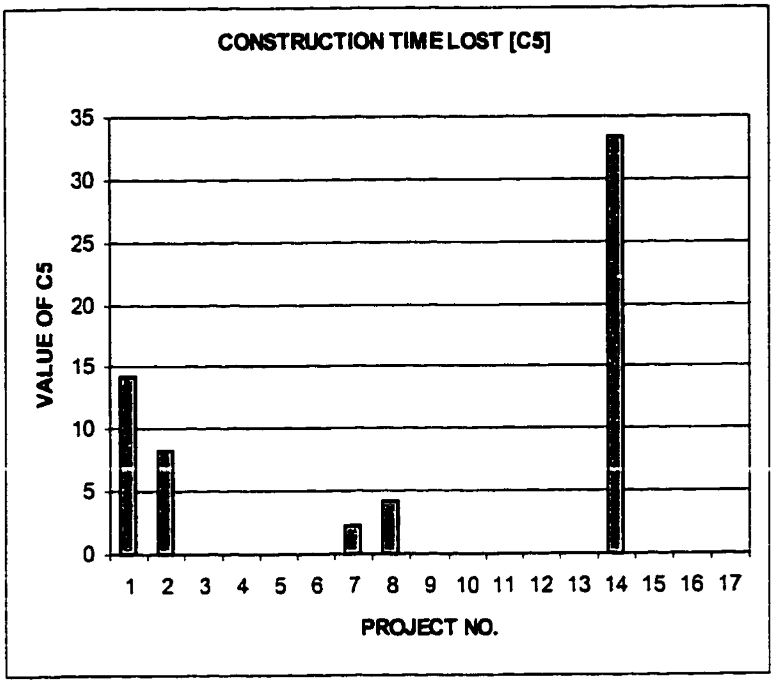


Figure 5.11 Construction Time Lost (C5)

Table 5.20 Construction Time Lost (C5)

Project No.	Construction Time Lost (C5)
1	14.29
2	8.33
3	0
4	X
5	X
6	X
7	2.2
8	4.17
9	X
10	0
11	0
12	0
13	X
14	33.33
15	0
16	X
17	X
Average	6.23
Std. Dev.	10.64

Note: X represents a missing value

5.2.8 Total Surplus (C11)

On calculating total surplus (C11), the following formula was used:

C11= (VUM/TPM)*100, where:

VUM= value of unused materials

TPM= total value of purchased materials

Total surplus (C11) measure, which weighs 25%, was found to average 1.14%, based on 13 respondents with 1.65 as a standard deviation. The highest surplus (5%) was also found in project 7. Projects number 9 and 11 (both of which have 50-74% completion) were found to have zero surplus. Total surplus was not known for some projects, namely projects number 3 and 8 because they were at 50-74 % completion. The overall surplus is considered acceptable.

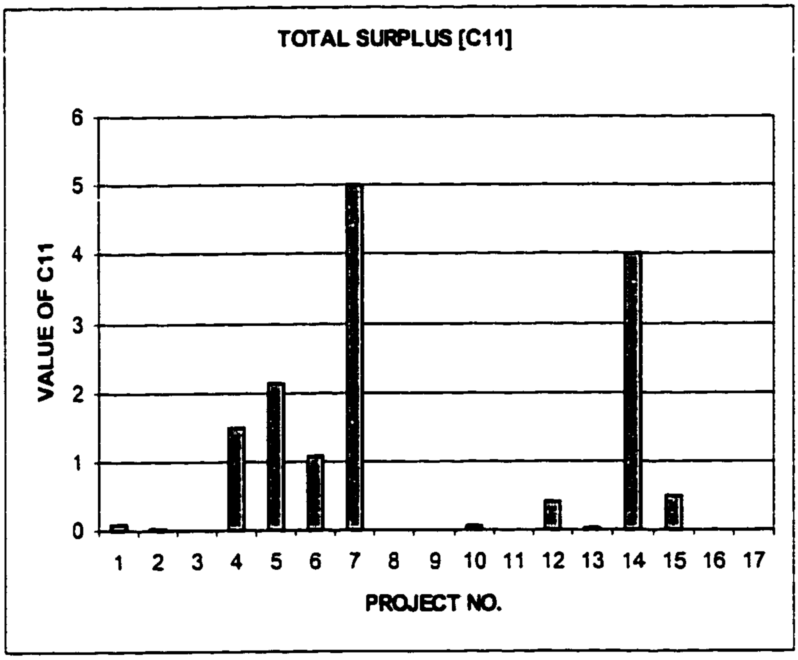


Figure 5.12 Total Surplus (C11)

Table 5.21 Total Surplus (C11)

Project No.	Total Surplus (C11)
1	0.1
2	0.015
3	X
4	1.5
5	2.14
6	1.08
7	5
8	X
9	0
10	0.071
11	0
12	0.398
13	0.029
14	4
15	0.5
16	X
17	X
Average	1.14
Std. Dev.	1.65

Note: X represents a missing value

5.3 Projects Ranking

During the field study, the need to compare the performance of each project with the others became very apparent. Project managers wanted to know how their projects performed with regard to other projects. In addition, the need to establish a benchmarking mechanism necessitates ranking the projects according to their performance.

The measures were divided into two groups, A and B, where Group A includes measures that are considered best when they are as low as possible, while Group B include measures that are considered best when they are as high as possible.

The average values for Group A measures were added for the projects and were ranked in ascending order of their total scores. The lower the score the project had, the higher the ranking it achieves. Consequently, the project with the lowest score is considered the best.

Similarly, the average values for Group B measures were added for the projects and were ranked in descending order of their total score. The higher the score the project had, the higher ranking it achieves. Consequently the project with the highest score is considered the best.

After giving each project a ranking number in its group, the ranking numbers for Group A were adjusted to take into account the difference in weight for both groups. Since the total weight for Group A was found to be 2.24 and the total weight for Group B was found to be 1.58, the difference - the adjusting factor - was found to be .66. For example, project number 6 was ranked the sixth in Group A with a ranking value of 3.96 and the second in Group B, 2.64 and 2 were added to give project number 6 a ranking value of 5.96. The ranking values were then sorted in ascending order, the lower the ranking value the project had the better. For example, project number 3 had a ranking value of 3.0, the lowest score among all, hence it was given an overall ranking of the best overall. (See Table 5.23.)

5.3.1 Group A Ranking

For Group A, project number 11 was considered the best with an average of 0, exactly the ideal value, while project number 4 was considered the worst in Group A, with the highest average, 58.59%. The average score for Group A was found to be 15.88%, and the standard deviation was found to be 13.54.

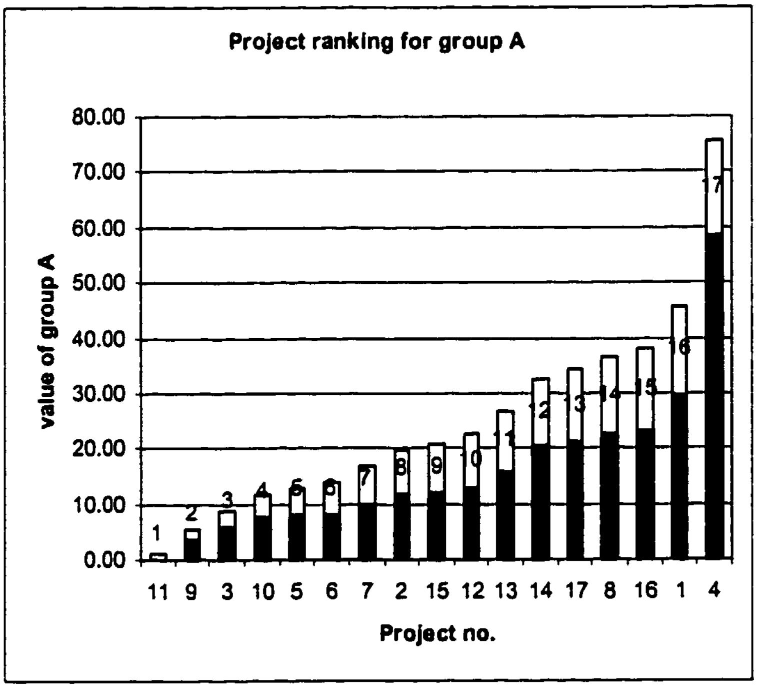


Figure 5.13 Project Ranking for Group A

Table 5.22 Project Ranking for Group A

Project No.	Average Of Group A Measures	Ranking No.
11	0.00	1
9	3.57	2
3	5.86	3
10	7.51	4
5	7.91	5
6	8.04	6
7	9.95	7
2	11.63	8
15	11.91	9
12	12.68	10
13	15.57	11
14	20.48	12
17	21.24	13
8	22.60	14
16	22.85	15
1	29.56	16
4	58.59	17
Average	15.88	
Std. Dev.	13.54	

5.3.2 Group B Ranking

In Group B, project number 3 was considered the best with an average of 99.96%, almost the ideal value, while project number 4 was considered the worst with an average of 55.26%. This project was also found to be the worst among group A. Project number 7 was not ranked because there are no values available for Group B measures.

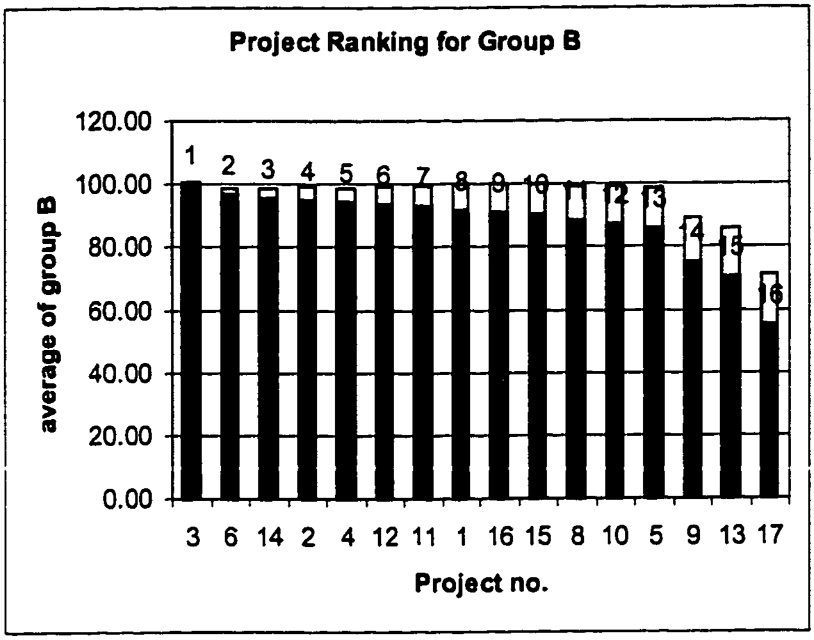


Figure 5.14 Project Ranking for Group B

Table 5.23 Project Ranking for Group B

Project No.	Average of Group B Measures	Ranking No.
3	99.96	1
6	97.11	2
8	95.59	3
9	95.21	4
10	94.05	5
14	93.66	6
13	92.75	7
11	91.99	8
1	90.89	9
16	90.19	10
2	88.45	11
12	87.50	12
5	85.91	13
15	75.35	14
17	70.80	15
4	55.26	16
7	X	
Average	87.79	
Std. Dev.	11.51	

Note: X represents a missing value

5.3.3 Overall Ranking

Table 5.24 Project Overall Ranking

Project No. [1]	Average A [2]	Ranking No.A [3]	Adjusting Factor [4]	Ranking Value A [5]=[5]*[4]	Average B [6]	Ranking No.B [7]	Ranking Value [8]=[5]+[7]	Overall Ranking [9]
3	5.86	3	0.66	1.98	99.96	1	3.0	1
6	8.04	6	0.66	3.96	97.11	2	6.0	2
11	0.00	1	0.66	0.66	92.75	7	7.7	3
2	11.63	8	0.66	5.28	95.21	4	9.3	4
14	20.48	12	0.66	7.92	95.59	3	10.9	5
12	12.68	10	0.66	6.60	93.66	6	12.6	6
10	7.51	4	0.66	2.64	87.80	12	14.6	7
9	3.57	2	0.66	1.32	75.35	14	15.3	8
15	11.91	9	0.66	5.94	90.19	10	15.9	9
4	58.59	17	0.66	11.22	94.05	5	16.2	10
5	7.91	5	0.66	3.30	85.91	13	16.3	11
1	29.56	16	0.66	10.56	91.99	8	18.6	12
16	22.85	15	0.66	9.90	90.89	9	18.9	13
8	22.60	14	0.66	9.24	88.45	11	20.2	14
13	15.57	11	0.66	7.26	70.80	15	22.3	15
17	21.24	13	0.66	8.58	55.26	16	24.6	16
7	9.95	7	0.66	4.62	X			
Average	15.88				87.81			
Std. Dev.	13.54				11.51			

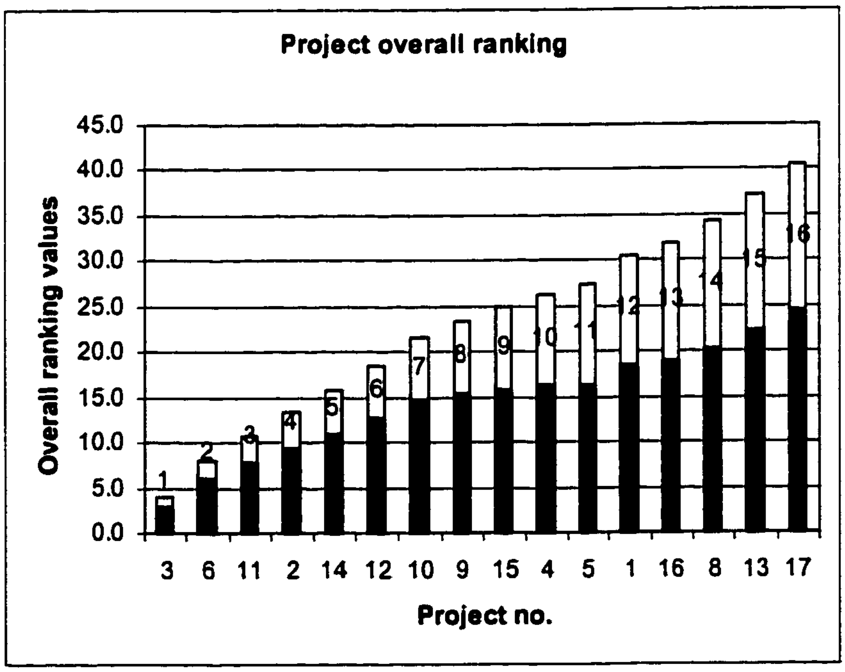
Group A Weight	2.24
Group B Weight	1.58
The Difference(adjusting factor)	0.66

Note: X represents a missing value

Table 5.23 consists of nine columns. The first column indicates the project number, the second the average of Group A measures, the third the ranking number, the fourth the adjusting factor, and the fifth one is the multiplication of column 3 by 4, giving the ranking value of Group A measures. Column number six and seven represent the average of Group B measures, and its ranking values. The eighth column adds up columns 5 and 7 and is listed in an ascending order. The last column indicates the overall ranking. The last two rows indicate the sum of the weight of both Group A and Group B measures as identified by Plemmons. (See Table 2.1.)

As shown in Table 5.23, project number 3 was ranked third in Group A measures and the first in Group B measures with the lowest ranking value of 3.0, hence it was considered as the best overall. Project number 9 came the second in the overall ranking, having scored second in Group A and fourth in Group B measures, giving an overall ranking value of 5.3. The third rank was for project number 6, which scored sixth in Group A and second in Group B. Project number 11, however, scored first in Group A but eighth in Group B, to become fifth in the overall ranking. Two projects (projects number 2 and 5) shared the same ranking values, both being ranked ninth in the overall ranking. Another two projects, number 16 and 15, shared the same ranking number, the twelfth. Project number 7 was ranked seventh in Group A, but in Group B, because no data was available, it was not ranked in the overall ranking.

The close ranking values in both groups clearly indicates that projects shared almost the same characteristics with regard to their materials



management process and consequently its effectiveness.

Figure 5.15 Project Overall Ranking

5.4 Projects Results

Below is the summary for all projects that were studied, along with the results of their key effectiveness measures.

5.4.1 Project Number 1

Table 5.25 Key Measurements for Project Number 1

Key Measurements	1	Average	Std Dev.
1- Material receipt problem (AC1) B	97.98	97.03	5.41
2- Warehouse inventory accuracy (AC3) B	90.00	92.37	7.03
3- Materials availability (AV1) B	95.00	95.04	4.64
4 Commodity vendor timeliness (T5) B	85.00	70.35	29.37
5 Jobsite rejections of tagged equipment (Q2) A	0.10	4.28	7.96
6 Procurement lead time (T1) A	100.00	32.36	48.73
7 Bid/evaluate/commit lead time (T2) A	100.00	21.58	25.52
8 PO to materials receipt duration (T3) A	22.00	23.00	24.37
9 Materials receiving processing time (T4) A	0.00	2.38	8.91
10 Materials withdrawal request lead-time(T7) A	0.00	24.29	31.06
11 Construction time lost (C5) A	14.29	6.23	10.63
12 Total surplus (C11) A	0.10	1.14	1.65
Group A Average	29.56		
Group A Standard Deviation	44.24		
Group B Average	91.99		
Group B Standard Deviation	5.71		

This project scored close to the average in the AC1 measure, 97.98% compared to the average of 97.03%. It scored 90% in the AC3 measure, which was below the average 92.37%. Its AV1 measure was 95%, which was almost the average 95.01%. It scored above average in the T5 measure. The average was 70.35%, while it scored 85% for the T5 measure. The project was good in managing all accuracy measures, AC1, AC3, and the availability measure AV1, as well as one measure of the timeliness, namely T5. It also scored better than average in the Q2 measure, which is a quality measure belonging to group A, scoring 0.1% compared to 4.28%. This means that the project experienced only 0.1% rejection of tagged equipment. The quality function was also reflected positively in other measures, namely accuracy and availability. The project did not seem to have any problem with the surplus measure, scoring 0.10% compared to the average 1.14%. It has, however, lost construction time due to unavailability of materials; it scored 14.29% compared to the average 6.23%. This result, higher construction lost time due to unavailability of materials, does not match the relatively high availability and accuracy measures, suggesting that there must be an error on calculating either the availability measure or the construction time lost measure. But since the accuracy measures were also high, one will have doubt on calculating the construction time lost measure.

The timeliness measures, T1, and T2, which are the actual versus planned lead-time of some materials functions, scored higher than the desired average. This means the actual lead-time for these measures was higher than the planned ones, which indicates an underestimation error performed by the project procurement group. On being compared with others, this project scored sixteenth and ninth in Groups A and B, respectively. Therefore it was overall ranked eleventh among the projects. This project was the only industrial project and has, along with project number 3, the highest project value of more than US$ 401 million.

5.4.2 *Project Number 2*

Table 5.26 Key Measurements for Project Number 2

Key Measurements	2	Average	Std Dev.
1- Material receipt problem (AC1) B	99.53	97.03	5.41
2- Warehouse inventory accuracy (AC3) B	X	92.37	7.03
3- Materials availability (AV1) B	95.20	95.04	4.64
4 Commodity vendor timeliness (T5) B	90.90	70.35	29.37
5 Jobsite rejections of tagged equipment (Q2) A	1.67	4.28	7.96
6 Procurement lead time (T1) A	0.00	32.36	48.73
7 Bid/evaluate/commit lead time (T2) A	0.00	21.58	25.52
8 PO to materials receipt duration (T3) A	33.00	23.00	24.37
9 Materials receiving processing time (T4) A	0.00	2.38	8.91
10 Materials withdrawal request lead-time(T7) A	(50)	24.29	31.06
11 Construction time lost (C5) A	8.33	6.23	10.63
12 total surplus (C11) A	0.02	1.14	1.65
Group A average	11.63		
Group A standard deviation	19.20		
Group B average	95.21		
Group B standard deviation	4.32		

Note: X represents a missing value

This project has the shortest duration period, falling into the 1-12 month period, and is also considered having low project value, with less than $US 100 million. It also has with project number 17, the lowest percentage completion level – 26-49%.

Looking into its Group B measures, the project scored well above average. The materials receipt problem (AC1) measure was found to be fifth among the seventeen projects. It scored 99.53%, which means that its accuracy with regard to materials receipt is excellent. Its warehouse inventory accuracy (AC3) measure was not available. Its commodity vendor timeliness (T5) measure to date was found to be 90.90%. The materials withdrawal request lead-time (T7) measure was found to be 50% in the negative side, which means that materials withdrawal process was faster than previously planned, indicating that either the planned withdrawal request lead-time was overestimated or that the warehouse staff worked some overtime hours. Its total surplus C11 was kept well under the average. It construction time lost was higher than average, scoring 8.33% compared to the average of 6.23%.

The project ranked eighth in Group A and the fourth in Group B, while its overall ranking was found to be fourth.

5.4.3 Project Number 3

Table 5.27 Key Measurements for Project Number 3

Key Measurements	3	Average	Std Dev.
1- Material receipt problem (AC1) B	99.87	97.03	5.41
2- Warehouse inventory accuracy (AC3) B	100.00	92.37	7.03
3- Materials availability (AV1) B	100.00	95.04	4.64
4 Commodity vendor timeliness (T5) B	X	70.35	29.37
5 Jobsite rejections of tagged equipment (Q2) A	0.00	4.28	7.96
6 Procurement lead time (T1) A	8.00	32.36	48.73
7 Bid/evaluate/commit lead time (T2) A	33.00	21.58	25.52
8 PO to materials receipt duration (T3) A	0.00	23.00	24.37
9 Materials receiving processing time (T4) A	0.00	2.38	8.91
10 Materials withdrawal request lead-time(T7) A	0.00	24.29	31.06
11 Construction time lost (C5) A	0.00	6.23	10.63
12 Total surplus (C11) A	X	1.14	1.65
Group A average	5.86		
Group A standard deviation	12.33		
Group B average	99.96		
Group B standard deviation	0.08		

Note: X represents a missing value

This project shares with other three projects the same percentage completion period - 50-74%, and with another project the relatively high project value of more than US$401 million Its Group B measures were found to be high, with the exception of the commodity vendor timeliness (T5) measure, which was not available. The result of this remarkable achievement was apparent in the construction time lost (C5) measure, where no construction time was lost due the unavailability of materials. Its bid/evaluate/commit lead-time (T2) measure took longer than anticipated and was above the average.

The PO to materials receipt duration (T3), materials receiving processing time (T4), and materials withdrawal request lead-time (T7) measures, were all found to be 0. The project ranked third in Group A, first in Group B, and its overall ranking was found to be first.

5.4.4 Project Number 4

Table 5.28 Key Measurements for Project Number 4

	Key Measurements	4	Average	Std Dev.
1-	Material receipt problem (AC1) B	99.04	97.03	5.41
2-	Warehouse inventory accuracy (AC3) B	85.00	92.37	7.03
3-	Materials availability (AV1) B	98.40	95.04	4.64
4	Commodity vendor timeliness (T5) B	93.75	70.35	29.37
5	Jobsite rejections of tagged equipment (Q2) A	0.06	4.28	7.96
6	Procurement lead time (T1) A	200.00	32.36	48.73
7	Bid/evaluate/commit lead time (T2) A	X	21.58	25.52
8	PO to materials receipt duration (T3) A	100.00	23.00	24.37
9	Materials receiving processing time (T4) A	0.00	2.38	8.91
10	Materials withdrawal request lead-time(T7) A	(50)	24.29	31.06
11	Construction time lost (C5) A	X	6.23	10.63
12	Total surplus (C11) A	1.50	1.14	1.65
	Group A average	58.59		
	Group A standard deviation	79.88		
	Group B average	94.05		
	Group B standard deviation	6.48		

Note: X represents a missing value.

This project shares with another 10 projects the same percentage completion level - 75-100, and with 5 projects the same duration period - 13-24 months. Hence the project is considered having common project status. Its warehouse inventory accuracy (AC3) measure was found to be 85%, a relatively low score. Its construction time lost (C5) measure was not known, otherwise the warehouse inventory accuracy would have affected it negatively. Its total surplus was found to be 1.50%, slightly above the average, 1.14%. Its Group A measures were found to be above average, with the procurement lead-time (T1) measure being the worst of all the projects. Consequently, this project ranked last in Group A, but fifth in Group B, and has the tenth rank overall.

5.4.5 Project Number 5

Table 5.29 Key Measurements for Project Number 5

	Key Measurements	5	Average	Std. Dev.
1-	Material receipt problem (AC1) B	98.65	97.03	5.41
2-	Warehouse inventory accuracy (AC3) B	95.00	92.37	7.03
3-	Materials availability (AV1) B	100.00	95.04	4.64
4	Commodity vendor timeliness (T5) B	50.00	70.35	29.37
5	Jobsite rejections of tagged equipment (Q2) A	3.25	4.28	7.96
6	Procurement lead time (T1) A	25.00	32.36	48.73
7	bid/evaluate/commit lead time (T2) A	25.00	21.58	25.52
8	PO to materials receipt duration (T3) A	0.00	23.00	24.37
9	Materials receiving processing time (T4) A	0.00	2.38	8.91
10	Materials withdrawal request lead-time(T7) A	0.00	24.29	31.06
11	Construction time lost (C5) A	X	6.23	10.63
12	total surplus (C11) A	2.14	1.14	1.65
	Group A Average	7.91		
	Group A Standard Deviation	11.74		
	Group B Average	85.91		
	Group B Standard Deviation	24.03		

Note: X represents a missing value.

This project shares with another 8 projects the same duration period - 25-48 months, and with 10 other projects the same percentage completion level - 75-100%. Its Group B measures were found to be above average with the exception of the commodity timeliness (T5) measure, which scored below average- 50%. It also had a relatively high surplus - 2.14% compared to the average, 1.14%. The equipment rejection rate of tagged equipment (Q2) was found to be high 3.25%. The project ranking for Group A was found to be fifth, thirteenth for Group B , while its overall ranking was found to be eleventh.

5.4.6 Project Number 6

Table 5.30 Key Measurements for Project Number 6

Key Measurements	6	Average	Std. Dev.
1- Material receipt problem (AC1) B	99.07	97.03	5.41
2- Warehouse inventory accuracy (AC3) B	95.00	92.37	7.03
3- Materials availability (AV1) B	99.40	95.04	4.64
4 Commodity vendor timeliness (T5) B	94.96	70.35	29.37
5 Jobsite rejections of tagged equipment (Q2) A	21.34	4.28	7.96
6 Procurement lead time (T1) A	(28.87)	32.36	48.73
7 bid/evaluate/commit lead time (T2) A	0.00	21.58	25.52
8 PO to materials receipt duration (T3) A	(5.00)	23.00	24.37
9 Materials receiving processing time (T4) A	0.00	2.38	8.91
10 Materials withdrawal request lead-time(T7) A	0.00	24.29	31.06
11 Construction time lost (C5) A	X	6.23	10.63
12 total surplus (C11) A	1.08	1.14	1.65
Group A average	8.04		
Group A standard deviation	11.99		
Group B average	97.11		
Group B standard deviation	2.46		

Note: X represents a missing value.

This project shares with 8 projects the same project duration period - 25-48 months, with 10 projects the same percentage completion level - 75-100, and with only one project the same value range – US$ 201-300 million. The average of Group B measures was found to be next to the best of all the projects. It scored an almost perfect score for AC1, and AV1. It experienced some rejection of tagged equipment (mainly wrong control valves scale), with 21.34% of equipment rejected compared to the average 4.28%. Group A measures were found to be perfect in three timeliness measures, namely T2, T4, and T7. Its surplus measure C11 was found to be 1.08% compared to the average of 1.14%. The actual procurement lead-time was shorter than the planned one, scoring 28.87% in the negative value, indicating that the procurement section may be overstaffed or that the planned time was not accurate. The project ranked second in Group B and sixth in Group A, while its overall ranking was found to be second.

5.4.7 Project Number 7

Table 5.31 Key Measurements for Project Number 7

	Key Measurements	7	Average	Std. Dev.
1-	Material receipt problem (AC1) B	X	97.03	5.41
2-	Warehouse inventory accuracy (AC3) B	X	92.37	7.03
3-	Materials availability (AV1) B	X	95.04	4.64
4	Commodity vendor timeliness (T5) B	X	70.35	29.37
5	Jobsite rejections of tagged equipment (Q2) A	X	4.28	7.96
6	Procurement lead time (T1) A	15.38	32.36	48.73
7	Bid/evaluate/commit lead time (T2) A	15.40	21.58	25.52
8	PO to materials receipt duration (T3) A	21.70	23.00	24.37
9	Materials receiving processing time (T4) A	0.00	2.38	8.91
10	Materials withdrawal request lead-time(T7) A	X	24.29	31.06
11	Construction time lost (C5) A	2.20	6.23	10.63
12	Total surplus (C11) A	5.00	1.14	1.65
	Group A Average	9.95		
	Group A Standard Deviation	8.73		
	Group B Average	#DIV/0!		
	Group B Standard Deviation	#DIV/0!		

Note: X represents a missing value.

This project was found to have the highest project value – US$ 301-400 million. It falls, however, under the 25-48 month duration group and 75-100% completion. The author faced many difficulties in coordinating the field study, as the project management team was very busy trying to bring the project back on track. Consequently many measures were not available. All Group B measures were unattainable. The project experienced the highest surplus (C11) - 5%. The project ranked seventh in Group A, but was not given an overall ranking.

5.4.8 *Project Number 8*

Table 5.32 Key Measurements for Project Number 8

Key Measurements	8	Average	Std. Dev.
1- Material receipt problem (AC1) B	99.00	97.03	5.41
2- Warehouse inventory accuracy (AC3) B	80.00	92.37	7.03
3- Materials availability (AV1) B	94.80	95.04	4.64
4 Commodity vendor timeliness (T5) B	80.00	70.35	29.37
5 Jobsite rejections of tagged equipment (Q2) A	0.00	4.28	7.96
6 Procurement lead time (T1) A	14.00	32.36	48.73
7 Bid/evaluate/commit lead time (T2) A	0.00	21.58	25.52
8 PO to materials receipt duration (T3) A	40.00	23.00	24.37
9 Materials receiving processing time (T4) A	0.00	2.38	8.91
10 Materials withdrawal request lead-time(T7) A	100.00	24.29	31.06
11 Construction time lost (C5) A	4.17	6.23	10.63
12 Total surplus (C11) A	X	1.14	1.65
Group A Average	22.60		
Group A Standard Deviation	37.06		
Group B Average	88.45		
Group B Standard Deviation	9.91		

Note: X represents a missing value.

This project shares with project number 6 the same project value – US$ 201-300 million, with 8 projects the same duration period - 25-48 months, and with 3 projects the same completion level - 50-74%. It scored the highest value for materials withdrawal request lead-time (T7) - 100%. Another measure connected to warehouse function was found to be the lowest of all the projects, namely warehouse inventory accuracy (AC3), which was found to be 80%. This clearly indicates a problem associated with the warehouse staff. This in turn affected the construction time lost, 4.17%, due to unavailability of materials. The rejection rate of tagged equipment, however, was found to be zero, which reflected the work of the quality assurance group. Its Group A measures were also found to be higher than average. The project ranked fourteenth in Group A and eleventh in Group B, while its overall ranking was found to be fourteenth.

5.4.9 Project Number 9

Table 5.33 Key Measurements for Project Number 9

	Key Measurements	9	average	Std. Dev.
1-	Material receipt problem (AC1) B	99.80	97.03	5.41
2-	Warehouse inventory accuracy (AC3) B	X	92.37	7.03
3-	Materials availability (AV1) B	95.00	95.04	4.64
4	Commodity vendor timeliness (T5) B	31.25	70.35	29.37
5	Jobsite rejections of tagged equipment (Q2) A	5.00	4.28	7.96
6	Procurement lead time (T1) A	0.00	32.36	48.73
7	Bid/evaluate/commit lead time (T2) A	0.00	21.58	25.52
8	PO to materials receipt duration (T3) A	0.00	23.00	24.37
9	Materials receiving processing time (T4) A	0.00	2.38	8.91
10	Materials withdrawal request lead-time(T7) A	(20.00)	24.29	31.06
11	Construction time lost (C5) A	X	6.23	10.63
12	Total surplus (C11) A	0.00	1.14	1.65
	Group A Average	3.57		
	Group A Standard Deviation	7.48		
	Group B Average	75.35		
	Group B Standard Deviation	38.27		

Note: X represents a missing value.

This project was the only refinery project. It shares with 5 projects the same project duration - 13-24 months; with 3 project the same completion - 50-74%; and with six projects the same project value less than US$ 100 million. The project suffered a low commodity vendor timeliness measure (T5), scoring 31.25% compared to the average, which was 70.35%. This means that there were many late deliveries. The rejection rate of tagged equipment was also high, at 5% compared to the 4%. average. This in turn affected the construction team, which will result in the loss of some construction time, unknown at this stage. The project ranked second in Group A and fourteenth in Group B, while its overall ranking was found to be eighth.

5.4.10 Project Number 10

Table 5.34 Key Measurements for Project Number 10

	Key Measurements	10	average	Std. Dev.
1-	Material receipt problem (AC1) B	80.00	97.03	5.41
2-	Warehouse inventory accuracy (AC3) B	100.00	92.37	7.03
3-	Materials availability (AV1) B	100.00	95.04	4.64
4	Commodity vendor timeliness (T5) B	70.00	70.35	29.37
5	Jobsite rejections of tagged equipment (Q2) A	0.00	4.28	7.96
6	Procurement lead time (T1) A	(20.00)	32.36	48.73
7	bid/evaluate/commit lead time (T2) A	(15.00)	21.58	25.52
8	PO to materials receipt duration (T3) A	(10.00)	23.00	24.37
9	Materials receiving processing time (T4) A	X	2.38	8.91
10	Materials withdrawal request lead-time(T7) A	X	24.29	31.06
11	Construction time lost (C5) A	0.00	6.23	10.63
12	total surplus (C11) A	0.07	1.14	1.65
	Group A Average	7.51		
	Group A Standard Deviation	8.79		
	Group B Average	87.50		
	Group B Standard Deviation	15.00		

Note: X represents a missing value.

This project shares with 6 projects the same project type; with 8 projects the same duration period - 25-48 months; and with 4 projects the same project value – US$ 101-200 million. Its commodity vendor timeliness (T5) measure was found to be almost the average, 70% compared to 70.35%. Its materials receipt problem (AC1) measure was found to be 80%, below the average of 97.03%. There was zero rejection of tagged equipment, and no construction time lost. The project ranked fourth in Group A and twelfth in Group B, while its overall ranking was found to be seventh.

5.4.11 Project Number 11

Table 5.35 Key Measurements for Project Number 11

	Key Measurements	11	Average	Std. Dev.
1-	Material receipt problem (AC1) B	100.00	97.03	5.41
2-	Warehouse inventory accuracy (AC3) B	85.00	92.37	7.03
3-	Materials availability (AV1) B	98.50	95.04	4.64
4	Commodity vendor timeliness (T5) B	87.50	70.35	29.37
5	Jobsite rejections of tagged equipment (Q2) A	0.00	4.28	7.96
6	Procurement lead time (T1) A	0.00	32.36	48.73
7	bid/evaluate/commit lead time (T2) A	0.00	21.58	25.52
8	PO to materials receipt duration (T3) A	0.00	23.00	24.37
9	Materials receiving processing time (T4) A	0.00	2.38	8.91
10	Materials withdrawal request lead-time(T7) A	0.00	24.29	31.06
11	Construction time lost (C5) A	0.00	6.23	10.63
12	total surplus (C11) A	0.00	1.14	1.65
	Group A Average	0.00		
	Group A Standard Deviation	0.00		
	Group B Average	92.75		
	Group B Standard Deviation	7.60		

This project shares with 6 projects the same project type - Oil & Gas; with 8 projects the same project duration period - 25-48 months; with 10 projects the same completion level - 75-100%; and with four projects the same project value – US$ 101-200 million.

This project had a perfect score in materials receipt problem (AC1) measure, a zero surplus, sharing the same score with project number 15, and also a zero rejection of tagged equipment. It had also a zero in construction time lost. This project ranked first in Group A and seventh in group B, while its overall ranking was found to be third.

5.4.12 Project Number 12

Table 5.36 Key Measurements for Project Number 12

	Key Measurements	12	Average	Std. Dev.
1-	Material receipt problem (AC1) B	97.57	97.03	5.41
2-	Warehouse inventory accuracy (AC3) B	X	92.37	7.03
3-	Materials availability (AV1) B	93.60	95.04	4.64
4	Commodity vendor timeliness (T5) B	89.80	70.35	29.37
5	Jobsite rejections of tagged equipment (Q2) A	0.00	4.28	7.96
6	Procurement lead time (T1) A	(20.00)	32.36	48.73
7	bid/evaluate/commit lead time (T2) A	(14.30)	21.58	25.52
8	PO to materials receipt duration (T3) A	(16.70)	23.00	24.37
9	Materials receiving processing time (T4) A	0.00	2.38	8.91
10	Materials withdrawal request lead-time(T7) A	50.00	24.29	31.06
11	Construction time lost (C5) A	0.00	6.23	10.63
12	Total surplus (C11) A	0.40	1.14	1.65
	Group A Average	12.68		
	Group A Standard Deviation	17.31		
	Group B Average	93.66		
	Group B Standard Deviation	3.89		

Note: X represents a missing value.

This project is another Oil & Gas project that shares the same duration period of 13-24 with five projects; the same completion of 75-100% with ten projects; and the same project value of less than 100 million USD with six projects.

This project has three measures having an actual lead-time less than the planned one, T1, T2, and T3. The project did not experience any lost in construction time, its surplus was kept well under the average, and it also had no rejection of tagged equipment.

It also has a good score in Group B. It ranked tenth among Group A and the sixth among group B, while its overall ranking was the sixth.

5.4.13 PROJECT NUMBER 13

Table 5.37 Key Measurements for Project Number 13

	Key Measurements	13	Average	Std. Dev.
1-	Material receipt problem (AC1) B	98.58	97.03	5.41
2-	Warehouse inventory accuracy (AC3) B	X	92.37	7.03
3-	Materials availability (AV1) B	93.90	95.04	4.64
4	Commodity vendor timeliness (T5) B	19.93	70.35	29.37
5	Jobsite rejections of tagged equipment (Q2) A	26.67	4.28	7.96
6	Procurement lead time (T1) A	25.00	32.36	48.73
7	Bid/evaluate/commit lead time (T2) A	25.00	21.58	25.52
8	PO to materials receipt duration (T3) A	16.70	23.00	24.37
9	Materials receiving processing time (T4) A	X	2.38	8.91
10	Materials withdrawal request lead-time(T7) A	0.00	24.29	31.06
11	Construction time lost (C5) A	X	6.23	10.63
12	Total surplus (C11) A	0.03	1.14	1.65
	Group A Average	15.57		
	Group A Standard Deviation	12.54		
	Group B Average	70.80		
	Group B Standard deviation	44.12		

Note: X represents a missing value.

This project was the only project with a duration of more than 49 months, but it still shares the same completion of 75-100% with ten projects and the same project value of US$ 101-200 million. Two measures are worthy of notice in this project. First, its commodity vendor timeliness (T5) measure was very low, with a score of 19.93% compared to the average 70.35%, which means there were a lot of late deliveries, sugesting its procurement staff did not do well in proactive expediting. It looks as though this project was very long, of more than 49 months duration, but at the same time, its value was not as high as one would expect.

Secondly, its rejection rate of tagged equipment (Q2) measure was very high, with a score of 26.67% compared to the average 4.28%. This project ranked eleventh in Group A and fifteenth in Group B, while its overall ranking was found to be last, in this case fifteenth.

5.4.14 Project Number 14

Table 5.38 Key Measurements for Project Number 14

	Key Measurements	14	Average	Std. Dev.
1-	Material receipt problem (AC1) B	98.76	97.03	5.41
2-	Warehouse inventory accuracy (AC3) B	X	92.37	7.03
3-	Materials availability (AV1) B	88.00	95.04	4.64
4	Commodity vendor timeliness (T5) B	100.00	70.35	29.37
5	Jobsite rejections of tagged equipment (Q2) A	2.56	4.28	7.96
6	Procurement lead time (T1) A	(34.00)	32.36	48.73
7	Bid/evaluate/commit lead time (T2) A	50.00	21.58	25.52
8	PO to materials receipt duration (T3) A	(20.00)	23.00	24.37
9	Materials receiving processing time (T4) A	0.00	2.38	8.91
10	Materials withdrawal request lead-time(T7) A	(20.00)	24.29	31.06
11	Construction time lost (C5) A	33.30	6.23	10.63
12	Total surplus (C11) A	4.00	1.14	1.65
	Group A Average	20.48		
	Group A Standard Deviation	17.85		
	Group B Average	95.59		
	Group B Standard Deviation	6.60		

Note: X represents a missing value.

This project shares the same duration period of 13-24 months with five projects; the same completion level of 75-100% with ten projects; and the same project value of less than 100 million USD with six projects.

This project had a perfect commodity vendor timeliness (T5) measure, scoring 100%, which means that the total number of deliveries were on time. Yet it lost construction time due to unavailability of materials, as its C11 measure was found to be 33.30, the highest of all the projects. This indicates that there is something wrong in reporting the commodity vendor timeliness measure. The project also experienced 4% of total surplus compared to the average 1.14%. The project ranked twelfth in Group A and third in Group B. Its overall measure, however was found to be fifth.

5.4.15 Project Number 15

Table 5.39 Key Measurements for Project Number 15

	Key Measurements	15	Average	Std. Dev.
1-	Material receipt problem (AC1) B	100.00	97.03	5.41
2-	Warehouse inventory accuracy (AC3) B	95.00	92.37	7.03
3-	Materials availability (AV1) B	87.50	95.04	4.64
4	Commodity vendor timeliness (T5) B	78.26	70.35	29.37
5	Jobsite rejections of tagged equipment (Q2) A	4.86	4.28	7.96
6	Procurement lead time (T1) A	25.00	32.36	48.73
7	Bid/evaluate/commit lead time (T2) A	20.00	21.58	25.52
8	PO to materials receipt duration (T3) A	33.00	23.00	24.37
9	Materials receiving processing time (T4) A	X	2.38	8.91
10	Materials withdrawal request lead-time(T7) A	0.00	24.29	31.06
11	Construction time lost (C5) A	0.00	6.23	10.63
12	Total surplus (C11) A	0.50	1.14	1.65
	Group A Average	11.91		
	Group A Standard Deviation	13.82		
	Group B Average	90.19		
	Group B Standard Deviation	9.47		

This project shares the same attributes of duration period, completion percentage, and project value with project number 14. The project experienced a rejection of tagged equipment equal to 4.86% compared to the average 4.28%. The project also had a big difference between the planned and the actual PO to materials receipt duration, as the T3 measure was found to be 33% compared to the average 23.00%. The project ranked ninth in Group A and tenth in Group B, while its overall ranking was found to be ninth.

5.4.16 Project Number 16

Table 5.40 Key Measurements for Project Number 16

	Key Measurements	16	Average	Std. Dev.
1-	Material receipt problem (AC1) B	87.67	97.03	5.41
2-	Warehouse inventory accuracy (AC3) B	98.68	92.37	7.03
3-	Materials availability (AV1) B	86.33	95.04	4.64
4	Commodity vendor timeliness (T5) B	X	70.35	29.37
5	Jobsite rejections of tagged equipment (Q2) A	0.00	4.28	7.96
6	Procurement lead time (T1) A	14.28	32.36	48.73
7	Bid/evaluate/commit lead time (T2) A	33.33	21.58	25.52
8	PO to materials receipt duration (T3) A	33.33	23.00	24.37
9	Materials receiving processing time (T4) A	(33.33)	2.38	8.91
10	Materials withdrawal request lead-time(T7) A	X	24.29	31.06
11	Construction time lost (C5) A	X	6.23	10.63
12	Total surplus (C11) A	X	1.14	1.65
	Group A Average	22.85		
	Group A Standard Deviation	15.21		
	Group B Average	90.89		
	Group B Standard Deviation	6.78		

Note: X represents a missing value.

This project, the second last in the study, shares the same attributes with projects number 14 and 15 in the completion percentage, and the project value, but for the duration period, was found to be 25-48 months. Four measures were not available due to some difficulties encountered during the study. The project had the same score 33.33%, for T2, T3, and T4.

The project ranked fifteenth in Group A and ninth in Group B, while its overall ranking was found to be thirteenth.

5.4.17 Project Number 17

Table 5.41 Key Measurements for Project Number 17

	Key Measurements	17	Average	Std. Dev.
1-	Material receipt problem (AC1) B	96.97	97.03	5.41
2-	Warehouse inventory accuracy (AC3) B	X	92.37	7.03
3-	Materials availability (AV1) B	X	95.04	4.64
4	Commodity vendor timeliness (T5) B	13.54	70.35	29.37
5	Jobsite rejections of tagged equipment (Q2) A	2.97	4.28	7.96
6	Procurement lead time (T1) A	(20.57)	32.36	48.73
7	Bid/evaluate/commit lead time (T2) A	14.28	21.58	25.52
8	PO to materials receipt duration (T3) A	39.62	23.00	24.37
9	Materials receiving processing time (T4) A	0.00	2.38	8.91
10	Materials withdrawal request lead-time(T7) A	(50.00)	24.29	31.06
11	Construction time lost (C5) A	X	6.23	10.63
12	Total surplus (C11) A	X	1.14	1.65
	Group A Average	21.24		
	Group A Standard Deviation	19.99		
	Group B Average	55.26		
	Group B Standard Deviation	58.99		

Note: X represents a missing value.

This project, the last in this field study, shares the same project duration of 13-24 months with five projects; the same completion level of 26-49% with another project; and the same project value of less than 100 million USD with six projects.

The project experienced late deliveries of materials, scoring the lowest in commodity vendor timeliness (T5) measure, and it scored 13.54% compared to the average 70.35%. Since the construction time lost (C5) measure was not known, the effect of having late deliveries on the construction operation was not known either. Similarly, the surplus measure was not known due to the fact that this project was still in its early stages, only 26-49%, complete.

The project ranked thirteenth in Group A and sixteenth in Group B, while its overall ranking was found to be sixteenth.

5.5 SHORTCOMINGS OF PLEMMONS MEASURES

While it was not within the scope of this study to evaluate Plemmons measures, several observations are noteworthy of mention here.

- All Group B measures, AC1, AC3, AV1, and T5 were found easily attainable and were relatively accurate, thanks to the availability of computers that made it easy for materials managers to retrieve data. Some measures of Group A, however, were found either difficult or very difficult to measure.
- Construction time lost (C5) measure was one example of this difficulty. It was left for the construction field supervisors to assess and calculate construction time lost due to unavailability of materials. Field supervisors usually instruct their staff to do other jobs while waiting for the planned activity to receive its required materials. In this case they might not consider this time as lost time. They would consider it lost only if it affected the master schedule.

- The PO to materials receipt duration (T3) measure appeared very difficult to assess, because different materials have different time duration and materials managers or procurement staff do not have this type of information readily available. They were tempted by their tight schedule to estimate this duration.
- The same thing can be said of procurement lead-time (T1), bid/evaluate/and commit (T2), and materials withdrawal request lead-time (T7) measures, all of which were found difficult to calculate and many project managers estimated these values to the best of their knowledge.
- Materials receiving processing time (T4) measure did not seem to mean any thing to project managers, as they all responded the same except for project number 16. Materials processed in one day was equal to the materials processed next day.

5.6 UTILIZATION PLAN FOR THE MODEL

For contractors or companies project managers willing to measure the effectiveness of their materials management process, several steps have to be carefully followed to ensure the study is being correctly carried out.

- Appoint an independent, knowledgeable leader, who, with a group of two persons, make up a team to coordinate the study.
- The team should develop a good understanding of the measures and identify the best way to collect the required information.
- The team should be well supported by the management to ensure the cooperation of all involved individuals.
- During the study, the team should explain clearly the meaning of each question in order to receive valid data.

- The team should verify the received data by taking some samples, i.e. they may physically count some materials and compare them with a system count to calculate warehouse inventory accuracy.
- The proposed model could be used by project managers to measure the effectiveness of their materials management in three stages, 26-49%, 50-74%, and 75-100% completion. The reason for measuring project at first stage is to identify the weaknesses of the materials management process and to rectify them before it is too late. Take another measurement at second stage to assess changes made according to the recommendations from the first stage study. The third stage study should give an overall indication about the project management from materials management point of view, and the impact it had on total surplus and project completion.

6. CONCLUSION

1. The study has indicated the existence of a sound and effective materials management process in the industrial projects studied.

2. All industrial projects studied were found to have been contracted under lump sum type of contract, a clear indication that it is the preferred type of contract for the industry in Saudi Arabia.

3. 88% of the projects were found to have from 13 to 48 month duration, and 71% of the projects had their values ranging from less than 100 to 200 million USD. One can find a formula that relates project cost to project duration in Saudi Arabia.

4. The average for Groups A and B measures were found to be 15.88% and 87.80% respectively. This is a strong indicator of a well-managed and effective materials management process of industrial projects.

5. This study, the first in its kind, to the best of the author's knowledge, establishes the foundation for a benchmarking mechanism in Saudi Arabia with regards to the materials management process in industrial projects.

6. The seventeen projects were ranked according to their performance. Project number 11 was found to be the best in Group A and project number 3 was found to be the best in Group B and overall.

7. The average for materials availability (AV1), which is an availability measure, was found to be 95%, a strong indication of an effective materials management process.

8. The materials receipt problem and the warehouse inventory measures were found to be 97% and 92% respectively. Both of these are accuracy measures and they reflect a well managed materials management process.

9. The average for jobsite rejection of tagged equipment (Q2), a quality measure was found to be 4.28%.

10. The construction time lost and the total surplus measures, both of which were cost measures, were found to have averages of 6.23%, and 1.14% respectively.

11. The averages for the timeliness measures namely procurement lead-time, bid/evaluate/commit lead-time, PO to materials receipt duration, materials receiving processing time, commodity vendor timeliness, and materials withdrawal request lead-time measures were found to be 32.36%, 51.58%, 23.00%, 2.38%, 70.35%, and 24.29% respectively.

12. The commodity vendor timeliness (T5) measure was found to be 70.35%, suggesting that efforts are required to improve this record.

7. RECOMMENDATIONS

Based on the foregoing paragraphs, the author recommends the following:

1. Construction companies are encouraged to utilize the developed measuring model to measure the effectiveness of their materials management process.
2. They also are encouraged to compare their projects with the community averages found during this study, in order to establish a benchmarking mechanism.

8. RECOMMENDATIONS FOR FURTHER STUDY

1. Further study is required to establish a formula which relates the project cost to the project duration.
2. Further study is required to evaluate the key effectiveness measures and their importance in Saudi Arabia's business environment.
3. A comparison study is required to measure the effectiveness of the materials management process between local and international construction companies.

REFERENCES

1. Bendell T., Kelly J., Merry T., and Sims F., 1993. "Quality: Measuring and Monitoring", Century Business.
2. BRT (The Business Roundtable), 1982."Modern Management Systems", A Construction Industry Cost Effectiveness Project Report, Report A-6, Nov., PP. 24-29.
3. BRT (The Business Roundtable), 1983."Report on Materials Management". CICE project, Appendix A-6.5 to Report A-6, February.
4. Burati J. L., Mathews M. F., and Satyanarayana N. K., 1991. "Quality Management in Construction Industry", Journal of Construction Engineering And Management, 117(2), 341-357.
5. Camp, Robert C., "Benchmarking: the Search for Industry Best Practices that Lead to Superior Performance", ASQC Quality Press, Milwaukee, WI, 1989.
6. CII (Construction Industry Institute), 1987. "Project Materials Management Planning Guide", Materials Management Task Force, 83-7, Doc. 27.
7. CII, 1986. "Cost and Benefits of Materials Management Systems", Materials Management Task Force, Publication 7-1, November.
8. CII, 1988. "Project Materials Management Primer", Materials Management Task Force, Publication 7-2, November.
9. Deborah Fisher, Susan Miertschin, and David Pollock, 1995," Benchmarking in Construction Industry", Journal of Management in Engineering, Jan/Feb, Vol. 11, No. 1
10. Early James W. 1988 "Managing Construction Materials Flow", Plant Engineering, Vol. 42, Sept. 1988 pp. 52-54
11. Early James W. 1988 "Who Manages Construction Materials ", Plant Engineering, Vol. 42, Aug. 1988 pp. 72-74

12. Finn H. Sandberg, 1997 "Using a Coding system to Improve Benchmarking", AACE International Transactions.

13. Firth D., J. Apple, R. Denham, J. Hall, P. Inglis, and AlSaipe, "Profitable Logistics Management", McGraw-Hill Ryerson Limited, Toronto, 1988.

14. Frederick B. Muehlhausen, 1991. "Construction Site Utilization: Impact of Material Movement and Storage on Productivity and Cost", AACE transactions.

15. George P. Moore and Gordon D. Hagendorf, 1994. "Using Measurement to Evaluate Improvement Efforts", AACE transactions.

16. H. Randolph Thomas, Victor E. Sanvido, and Steve R. Sanders, 1989." Impact of Materials Management on Productivity- A Case Study", Journal of Construction engineering and Management, Vol. 115, No. 3, September 1989.

17. Harrington H. James, "Business Process Improvement", McGraw-Hill Inc., New York, NY, 1991.

18. Hazem M. Alzarka, 1994. "Object-Oriented Methodology Applied to Materials Management Systems", Clemson University.

19. Ian E. Chandler, 1978. "Materials Management on Building Sites", Lancaster, NY: Construction Press.

20. IBC (International Benchmarking Clearinghouse), 1993. Brochure. American Productivity and Quality Center, Houston, TX.

21. Industrial Report, 1998, "Re-evaluating the GCC Unified Strategy for Industrial Development", Monthly Bulletin, Issue 209, October.

22. James C. Buckett, Ronald L., and Cynthia Wilson, 1991."Cradle-to-Grave Material Management", AACE transactions.

23. James J. O'Brien, and Robert G. Zilly, "Contractor's Management Handbook", McGraw-Hill book company.

24. James K. Plemmons and Lansford C. Bell, 1995. "Measuring Effectiveness of Materials Management Process", ASCE, Journal of Management in Engineering, Vol. 11,No. 6, Nov/Dec.

25. James K. Plemmons, (1995). "Materials management process measures and benchmarking in the industrial construction industry," Ph.D. thesis, Clemson University, Clemson, S.C.

26. James K. Plemmons, and Lansford C. Bell. "Measuring and benchmarking materials management effectiveness", 1994 AACE

27. John H. Berka, and William D. Conn, 1994. "Materials Management: A Comprehensive System", AACE Transactions.

28. Karen Thomas, 1999, "Saudi Arabia: No End to Saudi Oil Price Woes", The Middle East, Issue 286, January.

29. Khalid Al-Frayan, "Foreign Investment in the Saudi Industry, Part II", Al-nashra Al-sanaiyah, Issue 142.

30. Lansford C. Bell, and G. Stukhart (1987). "Costs and Benefits of Materials Management Systems," Journal of Construction Engineering and Management, Vol. 113, No. 2, June, PP. 222-234

31. Lansford C. Bell, and George Stukhart, 1986. "Attributes of Materials Management Systems", Journal of Construction Engineering and Management, Vol. 112, No. 1, March 1986.

32. Maloney W. F., 1990. "Framework for Analysis of Performance", Journal of Construction Engineering and Management, Vol. 116, No. 3, September 1990.

33. Moin Siddiqi, 1999, "Saudi Arabia: Financial Report", The Middle East, Issue 286, January.

34. Moore, George, (1996). "Effective Inventory Control To Improve Customer Service: Techniques In Place At Saudi Diesel Generators Co.

Ltd.", The Gulf's Third Annual Distribution & Materials Management Forum, Dubai. UAE.

35. N. M. Lema and A. D. F. Price, 1995, "Benchmarking: Performance improvement toward competitive advantage", ASCE, Journal of Management in Engineering, Jan/Feb.

36. Naief T.N.H Al-Otaibi, Ph.D. Dessertation1995. "A Knowledge-Based Systems Approach to Materials Management for Large Construction Projects", University of Toronto.

37. Pramod Mallick, Stephen W. Meador, Shangraw, Jr., and John R. Selman, 1994. "DOE Benchmarking for Cost Management", AACE transactions.

38. Roger Warrender, 1994. "Warehouse Management: The critical application of The 1990's", June 94, Industrial Engineering.

39. Rothman H., 1992. "You need not be big to benchmark", Nation's Business, Dec. 80(12), 64-65.

40. Sink Scott D., "Productivity Management", John Wiley & Sons Inc., New York, NY, 1985.

41. The NCB Economist, 1998, "The Saudi Construction Sector: An Expanding Role for Private Investment", Vol. 8, Issue 5, September/ October.

42. The NCB Economist, 1998, "WTO and The Globalization of the Middle East Enterprise", Vol. 8, Issue 2, March/ April.

43. Thomas R. Marquardt, 1994. "Total Cost Management Via Effective Materials Management", AACE Transactions.

44. Willborn, Walter, and T. C. Cheng, "Global Management of Quality Assurance Systems", McGraw-Hill, Inc., 1994.